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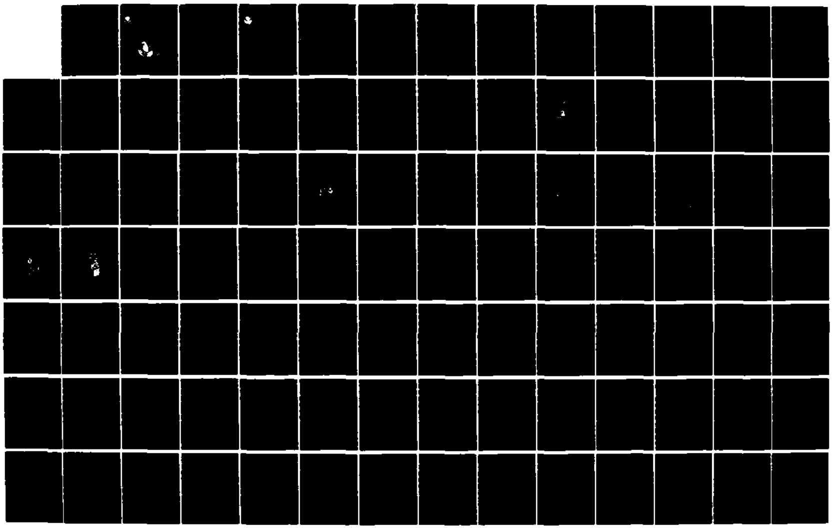

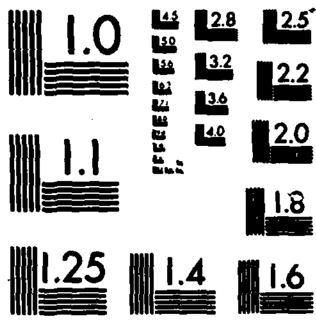

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ENVIROSAT–2000 Report

Plan for Space Station Polar-Orbiting Platform

June 1985

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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Plan for Space Station Polar-Orbiting Platform

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Washington, D.C.
June 1985

U.S. DEPARTMENT OF COMMERCE
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National Environmental Satellite, Data, and Information Service
John H. McElroy, Assistant Administrator

PLAN FOR SPACE STATION POLAR-ORBITING PLATFORM

ABSTRACT

This ENVIROSAT-2000 Report concerns utilization of the polar platform component of NASA's Space Station program. Issues covered in the report include instrument payloads, altitudes, orbits, serviceability, communications, and data processing. A scenario is set forth for operational utilization of the platform, including issues surrounding integration of operational and research missions. The discussion is broken down by discipline: oceanography, meteorology, land sciences, atmospheric sciences, and solar-terrestrial investigations. A cost analysis shows that performing NOAA operations from the polar platforms would prove extremely beneficial by replacing the expendable two Polar-orbiting Operational Environmental Satellite (POES) system that NOAA now maintains.

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PREFACE

The polar platform component of the National Aeronautics and Space Administration's (NASA) Space Station project, now scheduled for launch in 1993, will provide the scientific community with a permanent astronaut-tended vantage point in low Earth orbit from which to monitor the Earth's atmosphere, oceans, land masses, and space environment. As such, the polar platform can become the home for a family of remote-sensing instruments that are carried on current polar spacecraft or scheduled to fly within the next few years.

The National Oceanic and Atmospheric Administration (NOAA) is proposing an operational payload for the polar platform that will monitor the Earth's magnetic field, atmospheric temperatures and water vapor, ozone, aerosols, outgoing radiation, precipitation, sea surface temperature, sea ice, ocean chlorophyll, surface winds, wave height, ocean circulation, snow cover, land use, vegetation, crops, volcanoes, and the hydrologic cycle. Communications equipment proposed for the platform will provide routine interrogation of multidisciplinary environmental gauges and will monitor emergency transmissions from ships and planes in distress.

NOAA proposes to have this operational payload merged with the research sensors scheduled to be carried on the polar platform as part of NASA's Earth Observing System (EOS). The EOS payload will consist of advanced optical, microwave, radar, and laser sensors that initially will supplement and someday may replace the operational instruments proposed by NOAA. These advanced instruments eventually may permit routine monitoring of atmospheric chemistry, global winds, and space plasma, and may provide positive mineral identification from space.

In this report, it is proposed that two polar platforms be constructed to serve NOAA's needs--one to have a southbound morning equatorial crossing of 0900 local time (L) and the other to have a northbound afternoon equatorial crossing time of 1300 L. Both platforms would be in an 850 km sun-synchronous orbit. Communications would be handled through a combination of the Tracking and Data Relay Satellite System (TDRSS) and direct readout by a worldwide network of receiving stations. It is preferred that astronaut servicing of the platform be done at operational altitudes. The instrument payloads and even the platforms will be the result of extensive international cooperation.

This report consists of four chapters. Chapter I is an overview of the Space Station complex and the polar platform. Chapter II describes the proposed NOAA operational payload, including a detailed genealogy of instruments, and addresses issues involving repair and servicing, communications, data processing, opportunities for commercial entities, and international cooperation. Chapter III describes the benefits that accrue from merging operational and research missions on the platform. Finally, Chapter IV gives the cost rationale for use of the polar platform versus continued use of expendable polar metsats.

I. OVERVIEW OF SPACE STATION COMPLEX AND NOAA CONCEPT FOR POLAR PLATFORM

In his State of the Union message delivered on Jan. 25, 1984, President Reagan said, "Tonight, I am directing NASA to develop a permanently manned Space Station and to do it within a decade." NASA has developed a plan for the Space Station that involves three main components--a core platform, a co-orbiting platform, and a polar platform. The core platform will be continuously inhabited by astronauts and will be used for life science studies; materials production, research, and development; and as a servicing, assembly, and transportation mode. The second component, the co-orbiting platform, may be either astronaut-inhabited or tended. Requirements for this platform are still evolving, but may include applications of astrophysics, microgravity science, and space plasma physics. The third component, the polar platform, is the focus of this report. It is anticipated that the polar platform will be home to both research and operational missions directed toward the Earth sciences.

Unlike the other two components of the Space Station, the polar platform will be visited by astronauts only as part of repair and servicing missions--there will not be a continuous astronaut presence at the polar platform as it is now envisioned. The polar platform will be in an orbit inclined at an angle of nominally 98.2 degrees, whereas both the core and co-orbiting platforms will be in a low-inclination orbit (28.5 degrees). The polar platform also will be at a considerably higher altitude (700-900 km) than the other two Space Station components (500 km). For all these reasons, it becomes apparent that the polar platform must be launched and serviced separately. In fact, its one link with the other two components of the Space Station will be commonality of parts, design, and servicing techniques. This may enable savings through the use of a single assembly line for manufacture of some components. Thus, the polar platform will be a "derivative" of the core platform.

Figure I-1 shows a depiction of the Space Station complex. All components of the Space Station will be placed into orbit by the Space Transportation System (STS). Transportation between core and co-orbiting platforms will be accomplished through use of an Orbital Maneuvering Vehicle (OMV). Transportation from the STS up to the polar platform may be accomplished through use of an Orbital Transfer Vehicle (OTV). NOAA is proposing that the OTV have a "smart front end" to allow for the option of in situ platform servicing through the use of robotics.

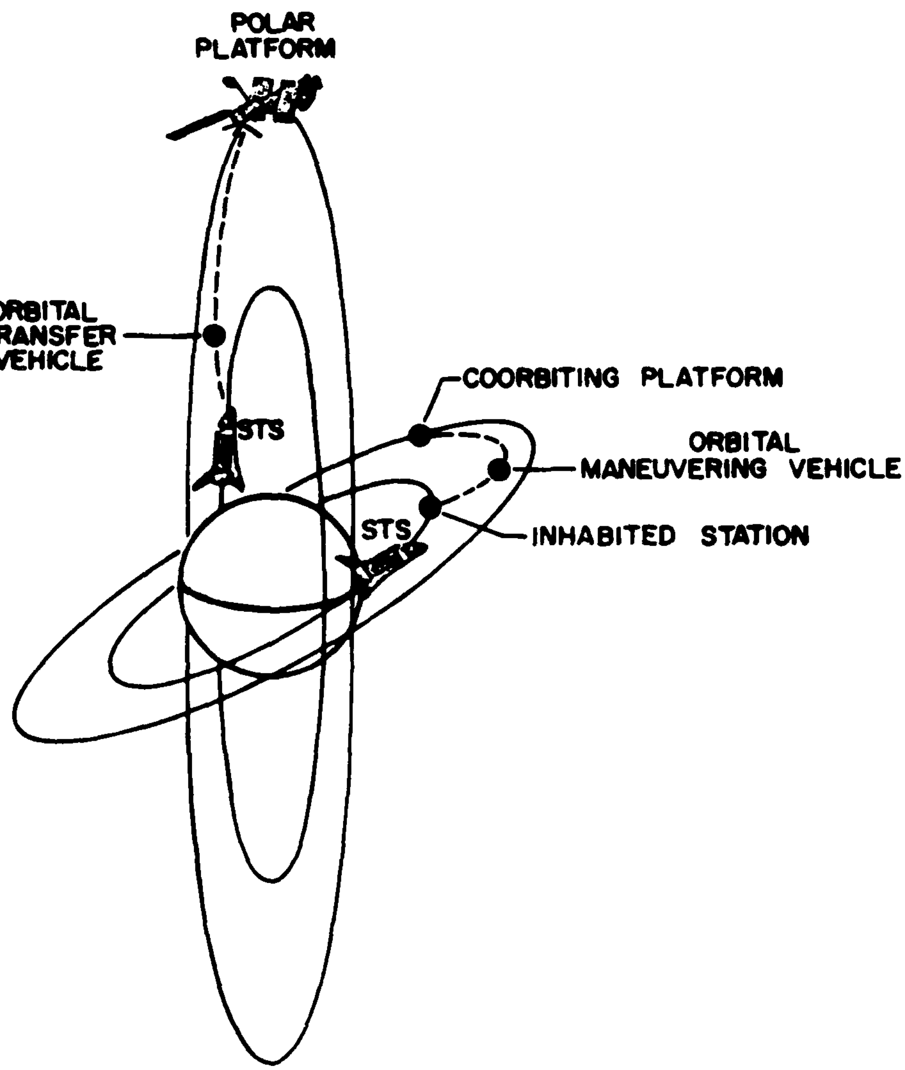

Figure I-1
Space Station Complex

A depiction of the Space Station polar platform mated with a NOAA operational payload is shown in Figure I-2. This diagram is consistent with the NASA reference configuration as shown in the Space Station Request for Proposals (Sept. 15, 1984). The reference configuration was meant to be the point of departure for all proposed designs. The platform shown here is designed to be carried in the STS cargo bay and deployed in a single STS mission. The platform initially will be able to supply customers with 5 kW of power, with a growth potential to 20 kW.

Communications will be handled through both the Tracking and Data Relay Satellite System (TDRSS) and direct readout by a worldwide network of readout stations. The platform will include a docking port for repair and servicing missions. The NOAA schematic also shows how instruments such as the synthetic aperture radar (SAR), advanced microwave radiometer (AMR), radar altimeter, and radar scatterometer can be placed on the spacecraft. The instrument bays beneath the spacecraft will house optical passive microwave and sounding instruments. These sensors are designed to monitor the following:

- Atmospheric temperature
- Water vapor
- Ozone
- Aerosols
- Sea ice and ice sheets
- Ocean chlorophyll
- Sea surface temperature
- Winds
- Waves and circulation
- Vegetation
- Crops
- Snow cover
- Geologic and hydrologic parameters

NOAA is proposing that two such polar platforms be made available for operational use. The afternoon (Alpha) platform will be in a sun-synchronous orbit with an equatorial crossing time of 1300 local time (L) ascending. The morning (Beta) platform

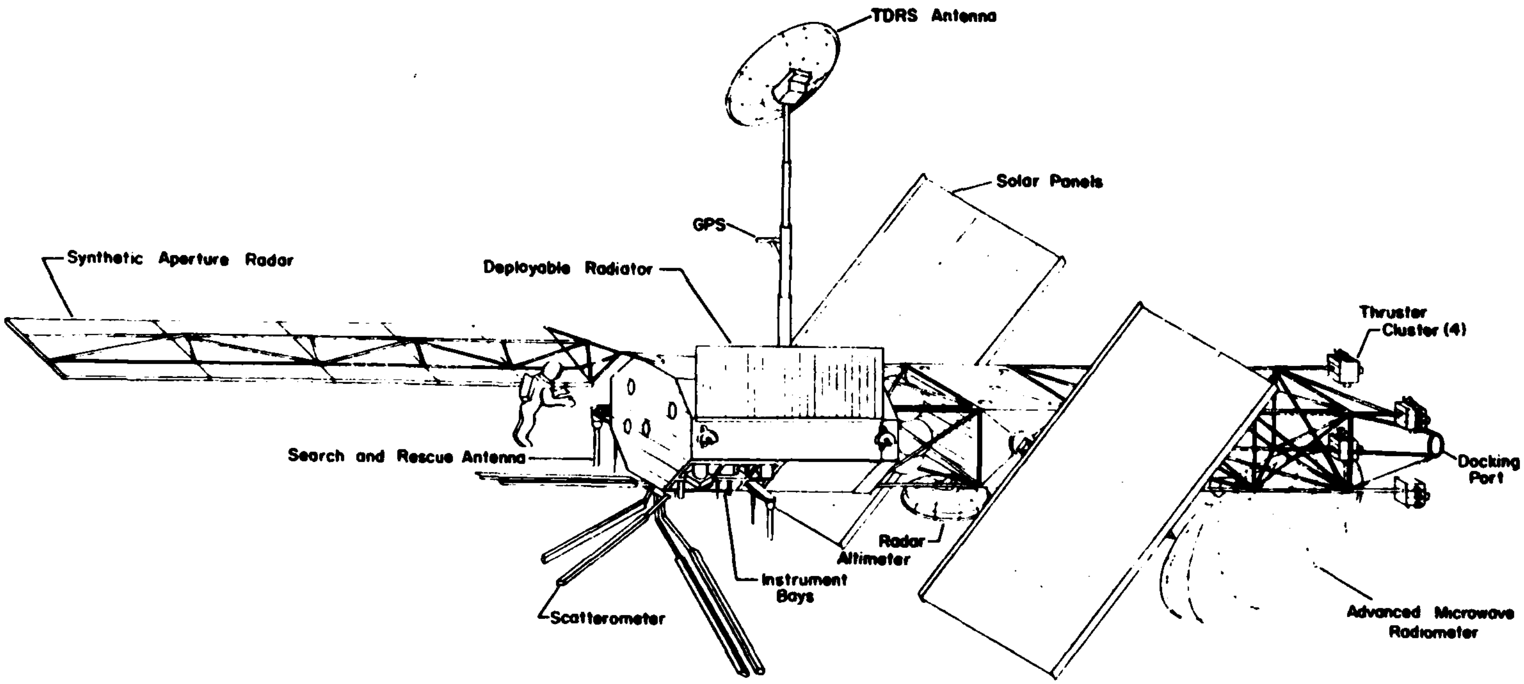

Figure I-2
Space Station Polar Platform
Mated With NOAA Operational Payload

also will be in a sun-synchronous orbit, but with an equatorial crossing time of 0900 L. Both will be at an altitude of roughly 850 km. Each platform will have a core operational payload of 11 instruments designed for meteorologic, oceanographic, and data services applications, and scientific research (see Fig. I-3).

The Alpha payload also consists of instruments that require maximum solar illumination to operate effectively, such as sensors to monitor ocean color, ozone and, for convenience, the Earth's radiation budget. The Beta platform has a high-resolution (possibly commercial) optical sensor for terrain monitoring. Land scientists prefer the morning orbit because it allows for Earth observations when cloudiness is at a minimum and also allows the use of shadows in delineation of landforms. Both the Alpha and Beta platforms will have a SAR instrument. Because the high data rate and power requirements of the SAR limits its operation duty cycle, it is proposed that the SAR on the morning platform (GEOSAR) be devoted solely to land monitoring and the SAR on the afternoon platform (SEASAR) be devoted solely to oceanic observations.

NOAA perceives that the data from platform instruments will be made available as an international global service. For the daily provision of a global environmental service, it is not reasonable to route all sensor data through the TDRSS. While projections can be made that the TDRSS will be a major data transmission channel, it cannot be the exclusive channel. It is not technically or economically feasible to route all sensor data through White Sands, New Mexico--perhaps from the other side of the world--when the people most in need of timely data are immediately below the polar platform. A varied, distributed user community must be served in equally varied, distributed ways. Figure I-4 is intended to depict the most likely situation that will exist in the 1990's.

For weather and oceanographic data, perhaps the most critical aspect is timeliness. Advanced warning of the onslaught of severe storms is obviously one of the most important functions that an Earth observation system can perform. In a less dramatic example, yet an important one, modern society is becoming similarly susceptible to disruption by natural events. Whether for land or maritime operations, society needs more sophisticated information about the weather and oceans. Thus, over the years, a number of direct broadcast services have evolved in the NOAA environmental satellites. They include the medium-resolution automatic picture transmissions that serve as the principal source of weather data in many developing countries. These countries have no means of access to data from a ground station in the United States and no funds to pay for long-distance telecommunication satellite

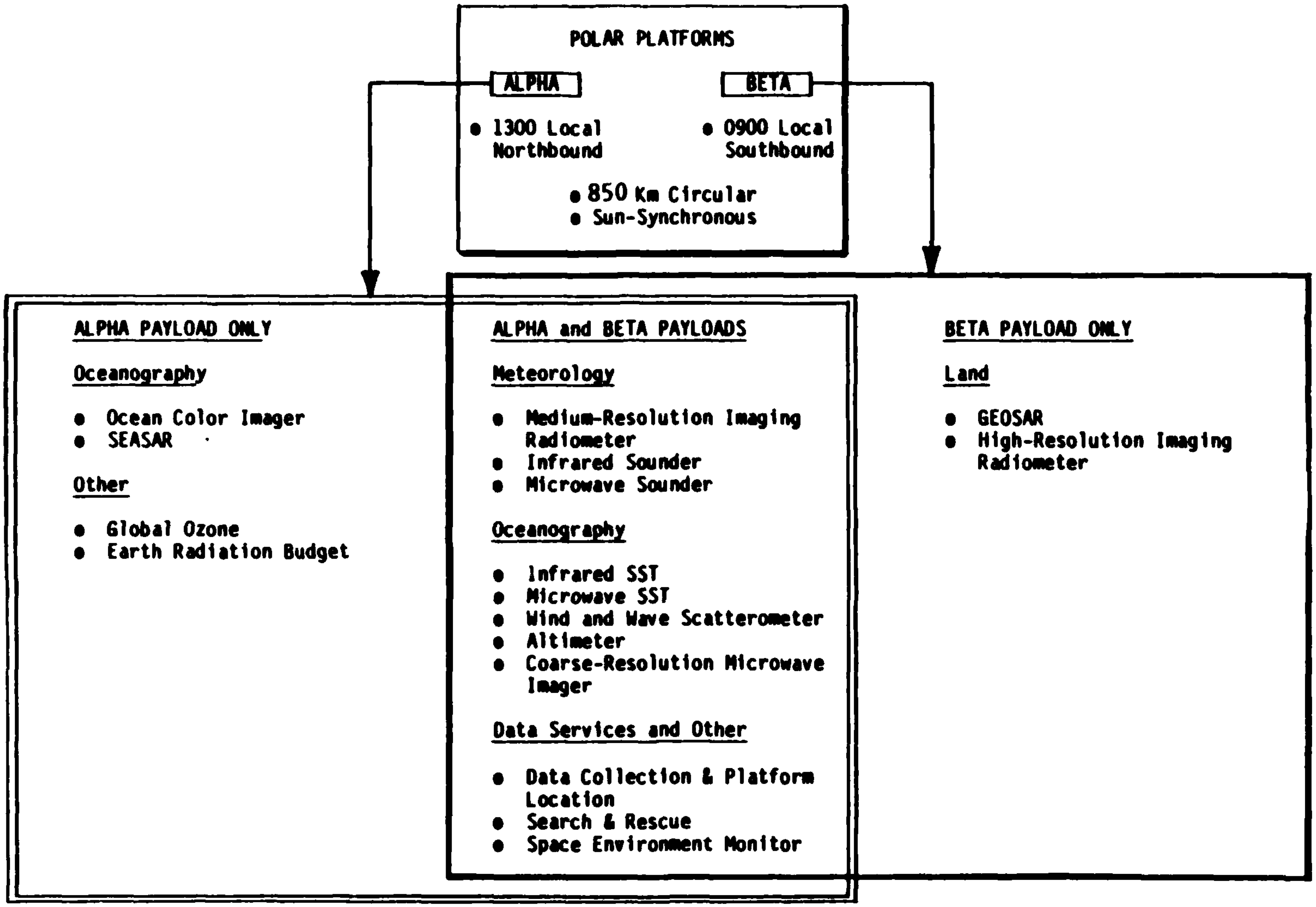

Figure I-3
Alpha and Beta Platforms
With a Core Operational Payload of 11 Instruments

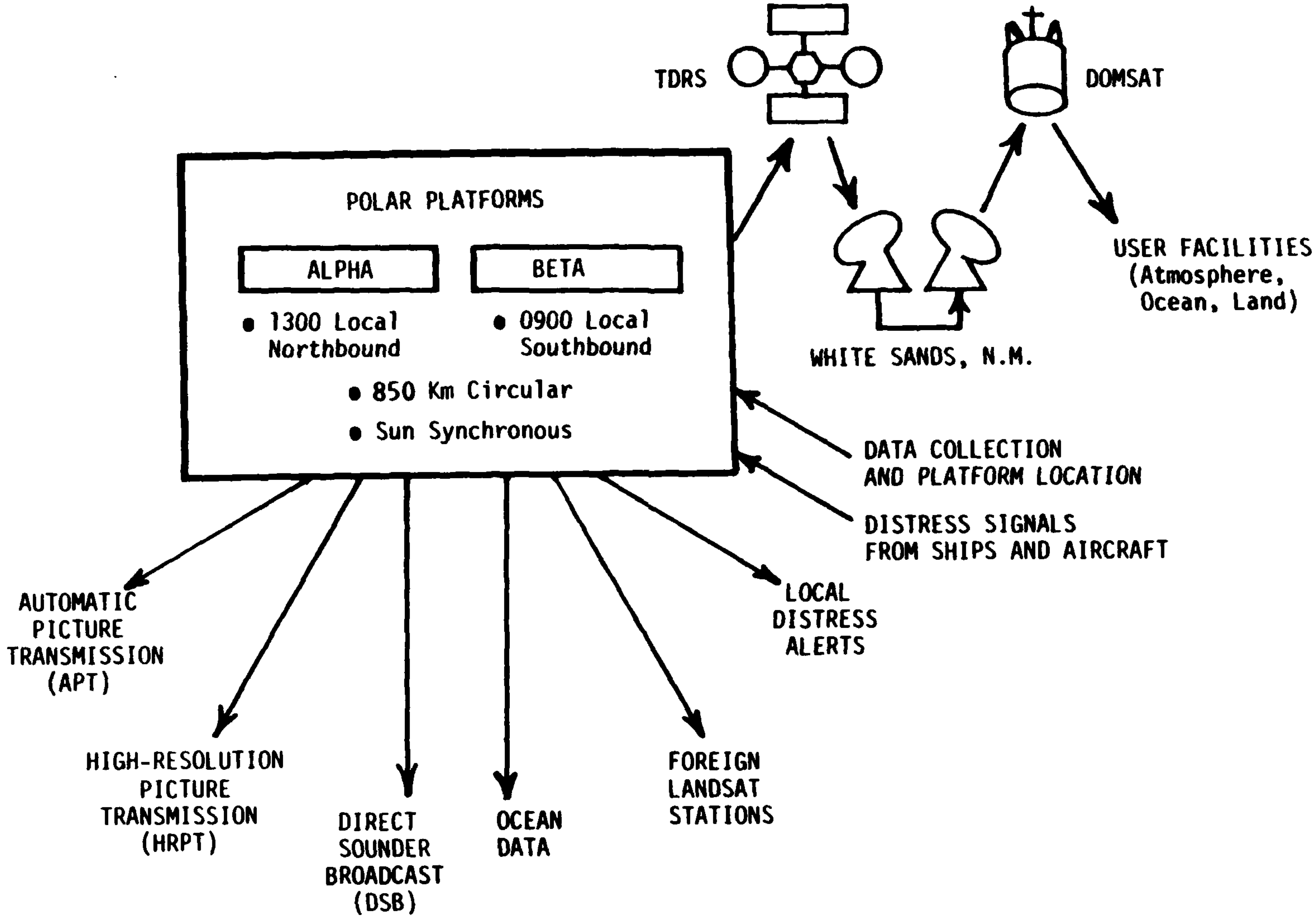

Figure 1-4
Data Dissemination Channels From the Polar Platform

channels, even when they are available in the region.

More sophisticated users employ high-resolution picture transmission stations or direct sounder broadcast stations to gain access to the better quality data that are beyond the capabilities of the developing countries but are very important to the needs of more developed societies. Again, the most timely data are taken when the satellite is directly overhead, and to terminate the current practice of continuous direct readout would be controversial under the best of circumstances and quite possibly inhumane if it resulted in the denial of a timely warning of a severe natural event.

II. UTILIZATION OF POLAR PLATFORM FOR OPERATIONAL EARTH OBSERVATIONS

A. INTRODUCTION

The recent decision to proceed with the development of a manned Space Station program may provide a new vantage point in space from which to monitor operationally the Earth's atmosphere, oceans, and ice and land masses. There are three principal elements to NASA's planned Space Station program:

- The permanently manned Space Station and its peripheral equipment in a low-altitude orbit at 28.5 degrees inclination
- An astronaut-tended co-orbiting platform in the same orbit to be used for materials processing and other experiments
- An astronaut-tended platform in near-polar, sun-synchronous orbit

In this report, the last element will be referred to simply as the "polar platform" and is of primary interest to NOAA governmental missions. The other two elements may satisfy some research needs in Earth observations or may be used as a base for the staging of geostationary missions, but they are not directly applicable to operational Earth observations.

The thesis of this chapter is quite simple and straightforward, namely, that the polar platform can be a major step in operational Earth observations--if it is explicitly designed to be such a step from the very outset--and the operational payload for the platform is essentially known today. Hypothetical payloads and speculative missions are not required for the planning of an operational polar platform. The payloads and requirements of the 1990's are known today and will be the direct result of the successful flight of operational and research missions during the 1980's. The development of a useful polar platform that can produce dramatic advances in the practical applications of space systems at the beginning of the 1990's should begin now. It is only a matter of setting this objective as a priority goal of the Space Station program.

The manner in which operational instruments can evolve from current and planned missions to the space platform is discussed in the next few paragraphs. Figure II-1 provides a guide to the evolutionary path the instruments will follow from their initial flights to deployment on the platform. This figure shows U.S. missions and two foreign missions,

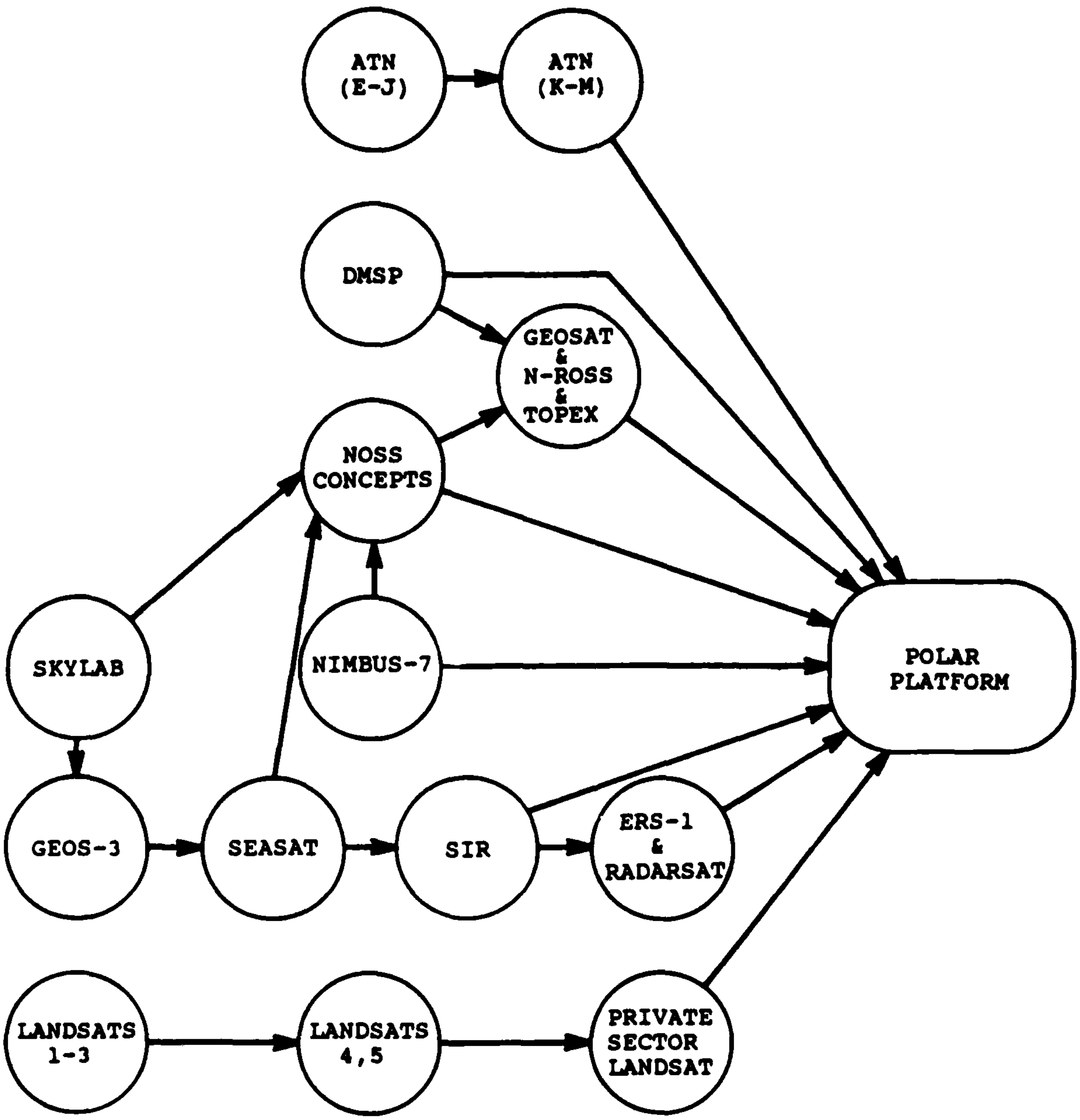

Figure II-1
Flow of Instruments to Polar Platform

Europe's Remote Sensing Satellite (ERS-1), and Canada's Radarsat. They are vital links in this progression. There are other foreign missions that will contribute to the progression, notably those of Japan, but a sufficient number of missions are shown in Figure II-1 to convey adequately the principal message of this paper.

The payload that is discussed is the operational payload--not the accompanying research instrument payload that also will be present. Although some of the instruments described are presently in a research stage, it is assumed that they will be ready for routine operational use during the era of the polar platform. A review of the platform servicing and data system characteristics required, and the opportunities available for commercial firms and international cooperation, follows the discussion of the payload.

B. ADVANCED TIROS-N SPACECRAFT

NOAA's Advanced TIROS-N (ATN) spacecraft is the current operational polar-orbiting environmental satellite. Figure II-2 shows a line drawing of the ATN. Any discussion of the evolution of instruments from a current operational mission to a polar platform must begin with an examination of the payload of the ATN. The ATN carries instruments whose heritage dates back to the launch of the first meteorological satellite on April 1, 1960. The environmental instruments can be categorized conveniently into four functional areas:

- Sounding. Profiles of atmospheric temperature and water vapor as a function of altitude.

- Imaging. Multispectral measurements of upwelling radiation in image format, whether recorded as an image or in digital form.

- Data collection. Capture of environmental data from in situ sensor systems that transmit to the overflying spacecraft.

- Space environment monitor. Measurement of the Earth's near-space radiation environment.

These function categories will remain useful at least beyond the next decade, even though the particular instruments that satisfy the needs of a given category will evolve with time. Table II-1 lists the principal characteristics of the ATN and its instrument payload. Because these instruments are used in preparing daily weather forecasts and warnings, as well as for other purposes, they are permanent Earth-observing systems that must be maintained in orbit to provide continuity with the past, present, and future environment events, whose time

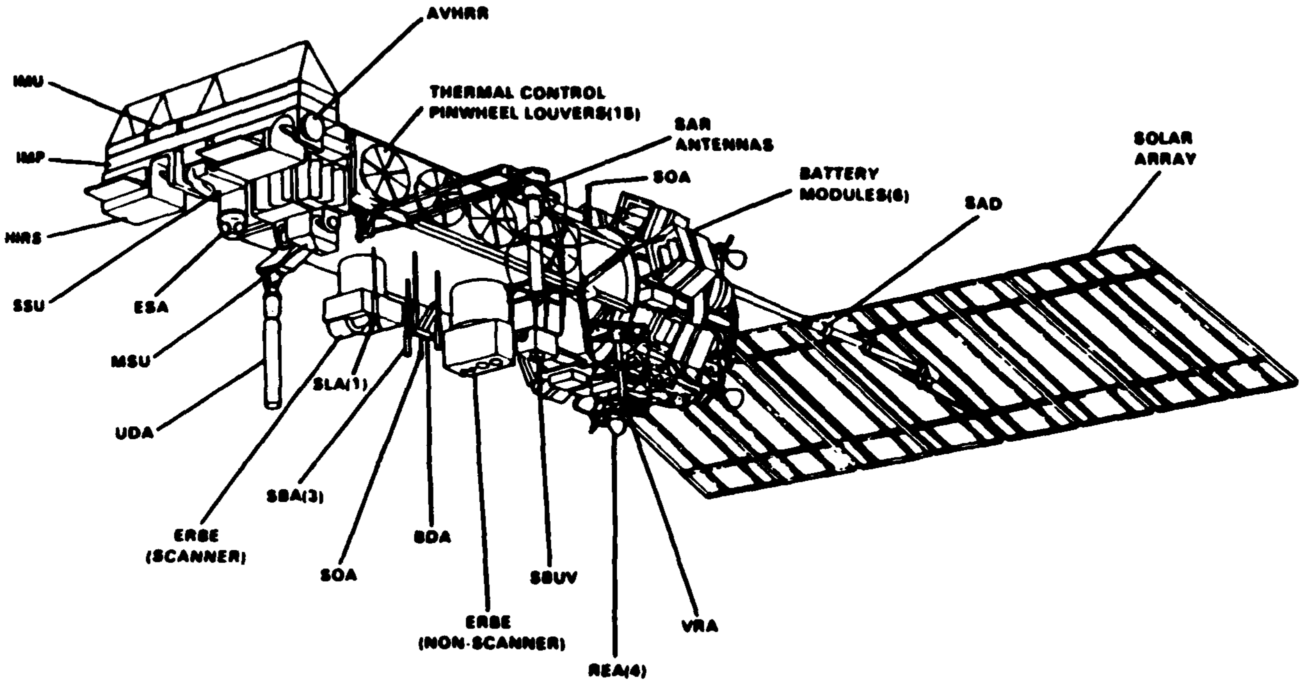

Figure II-2
Line Drawing of Advanced TIROS-N (ATN)

Table II-1
TIROS-N/ATN Sensors

Sensor	Number of Channels/Frequencies	Spectral Range/ Frequency Range	Resolution	Swath Width	Power Requirements
AVHRR (Advanced Very High Resolution Radiometer)	5	0.58 to 12.5 μm	1.1 km	2,700 km	25.7 W
HIRS/2 (High-Resolution Infrared Radiation Sounder)	20	4.3 to 15 μm	17.4 km	2,240 km	25 W
SSU (Stratospheric Sounding Unit)	3	NA	147 km	1,473 km	15 W
MSU (Microwave Sounding Unit)	4	50.3 to 57.05 GHz	109 km	2,347 km	30 W
Argos (French Data Collection and Platform Location System)	NA	136.77 and 137.77 MHz	NA	2,500 km (radius)	3 W
SAR (Search and Resc	NA	121.5 and 24.30 MHz	NA	2,000 km (radius)	57.2 W
SBUV (Solar Backscatter Ultra-violet Radiometer)	12	252 to 339.8 nm	169.3 km (11.3 degree IFOV)	—	12 W
ERBE (Earth Radiation Budget Experiment)	8	0.2 to 50 μm	67.5 km (3 x 4.5 degree IFOV)	Horizon to horizon	45 W
SEM (Space Environment Monitor)	NA	NA	NA	NA	8.4 W

Table II-1 (concluded)
TIROS-N/ATN Sensors

Sensor	Weight	Dimensions	Data Rate	Application
AVHRR	27.3 kg	0.30 x 0.64 x 0.32 m	2.66 Mbps	Sea surface temperature, cloud delineation, vegetation, sea ice, snow cover, aerosols
HIRS/2	33.2 kg	0.41 x 0.65 x 0.46 m	2.88 kbps	Atmospheric temperature, water vapor, ozone profiles
SSU	12.5 kg	0.27 x 0.29 x 0.26 m	480 bps	Measurement of upper atmosphere weighting functions
MSU	31.8 kg	0.58 x 0.38 x 0.23 m	320 bps	Measurement of atmospheric temperature profile under cloud-covered conditions
Argos	--	--	400 bps	Collection and transmittal of environmental data from guages on land and at sea
SAR	39.2 kg	--	2.4 kbps	Broadcast of distress signals from planes and ships
SBUV	38.2 kg	0.50 x 0.31 x 0.36 m 0.33 x 0.22 x 0.31 m	320 bps	Vertical distribution of ozone
ERBE	61 kg	0.46 x 0.50 x 0.61 m 0.35 x 0.40 x 0.59 m	1,120 bps	Earth Radiation Budget on synoptic and planetary scale
SEM	13.6 kg	0.13 x 0.12 x 0.36 m 0.19 x 0.21 x 0.12 m 0.07 x 0.30 x 0.28 m	160 bps	Monitoring of solar emissions and the variability of the Earth's magnetic field

scales range from minutes to years. Further, the present system configuration employs two daytime observations daily and, hence, two equatorial crossing times.

The presence in orbit of two spacecraft improves the robustness of the system and makes it less subject to losses of data continuity. The spacecraft characteristics and the data produced are described in detail elsewhere (refs. 1, 2, and 3). The characteristics shown in Table II-1 will be employed through NOAA J, the third in the most recent procurement of polar orbiters.

The next procurement of polar-orbiting environmental satellites, NOAA K through M, continues the mission of the ATN series and augments it through the replacement of the obsolete Microwave Sounding Unit (MSU) and Stratospheric Sounding Unit (SSU) sensors by the Advanced Microwave Sounding Unit (AMSU). The ATN configuration will be retained, and a major block change is planned to be made after NOAA M. NOAA's intention is to employ the block change to convert to operational use of the polar platform. The characteristics of the instrument payload are given in Table II-2. They are essentially the same as the preceding satellite, with the exception of the addition of two sensors, the AMSU and an Ocean Color Instrument (OCI), a slight modification to the Advanced Very High Resolution Radiometer (AVHRR) bands, and a modest increase in the capacity of the Argos system.

As shown on the flow chart in Figure II-1, AVHRR, AMSU, OCI, High Resolution Infrared Radiation Sounder (HIRS), Argos data collection and platform location system, satellite-aided search and rescue (SARSAT) system, and direct data transmission functions will be carried from NOAA H through J to NOAA K through M and on to the polar platform. The same instrument categories mentioned earlier apply, with the addition of one for the SARSAT system. This sequence obviously is dependent upon the schedule for the deployment of a polar platform.

The ATN satellites have meteorological observations as their first objective rather than as the exclusive objective. The instruments that provide meteorological and ocean observations also provide measurements of sea surface temperature, ocean color, sea ice, and snow cover, and an assessment of the condition of the Earth's vegetation. Fishing fleets use the data to determine areas having a greater likelihood for a sizable catch. Maritime shippers use the data to determine the most fuel-efficient routes--either by avoiding opposing currents or joining favorable ones. Drought monitoring aids in the projection of later crop shortages and the identification of areas where foodstuffs should be pre positioned in anticipation of those shortages.

Table II-2
NOAA K and M Sensors

Sensor	Number of Channels/Frequencies	Spectral Range/ Frequency Range	Resolution	Swath Width	Power Requirements
AMSU-A (Advanced Microwave Sounding Unit)	15	23 to 90 GHz	40 km	2240 km	110 W
AMSU-B	5	90 to 183 GHz	15 km	2240 km	70 W
OCI*	TBD	TBD			

Sensor	Weight	Dimensions	Data Rate	Application
AMSU-A	50 kg	0.61 x 0.71 x 0.30 m 0.71 x 0.61 x 0.91 m	3 kbps	All-weather atmospheric profiles (temperature)
AMSU-B	27.3 kg	0.50 x 0.64 x 0.66 m	6 kbps	All-weather atmospheric profiles (water vapor and liquid water content), active precipitation, and surface ice
OCI	TBD			

Note: NOAA K and M will carry all instruments listed under advanced TIROS-N (Table II-1) with the exception of the SSU, MSU, and ERBE. The AVHRR will gain a sixth channel in the 1.6-micron range. The Argos system may be expanded to accommodate more platforms.

* OCI is an FY87 NOAA budget initiative.

The sensors are used also in analyzing insect breeding grounds, soil moisture, volcanoes, and either the potential for or the existence of brush and forest fires (ref. 4). These are only some of the nonmeteorological applications of environmental satellite data. As noted previously, the satellites also serve as the home for the search and rescue system that directs aid to crashed aircraft and ships in distress. The multidisciplinary nature of the ATN satellites and the application of their payload will be carried over to the polar platform.

In addition to the operational sensors, NOAA F and G will carry two experimental sensors in support of the climate research program, the Solar Backscatter Ultraviolet (SBUV) radiometer and the Earth Radiation Budget Experiment (ERBE). The SBUV measures global ozone distributions, while the ERBE studies the radiation balance between incoming and outgoing energy. These two sensors will be used in some form in continuing operations to support the necessarily long-term measurements of the climate program and, therefore, are a source of measurement requirements for the polar platform.

A final element that should be noted is that the satellites carry subsystems supplied by foreign governments at no cost to the United States. The United Kingdom has provided the SSU for many years and is now developing a major section of the AMSU. France provides the data collection and platform location system, Argos. Canada and France provide the search and rescue transponder and onboard processor, respectively. Canada also is examining the provision of an instrument that would serve as the long-term follow-on to the SBUV and would continue the monitoring of the global ozone distributions.

Thus, the ATN satellites are international in their makeup and multidisciplinary in their application. Further, hundreds of ground stations in numerous countries receive data directly from the satellites, so the application of their data is even more international than their makeup. Therefore, from some perspectives, a significant step already has been taken toward a polar platform. Indeed, if the ATN satellites were serviceable--and NASA's STS were capable of providing servicing at that altitude--there would be little that distinguishes them from a small-scale polar platform.

C. DEFENSE METEOROLOGICAL SATELLITE PROGRAM

The Department of Defense (DOD) has its own polar-orbiting weather satellite system called the Defense Meteorological Satellite Program (DMSP). The satellite is similar in construction to the ATN, but employs a different instrument payload. Military support requirements differ from those of the civil sector and lead to payloads that are quite dis-

similar. One of its planned instruments, the Special Sensor Microwave Imager (SSM/I), is deserving of note because it is also planned to be a part of the Navy Remote Ocean Sensing System (N-ROSS). The SSM/I provides all-weather measurements of ocean surface wind speed, sea ice information, and precipitation amount.

The DMSP also carries a temperature sounding system called the Special Sensor Microwave Temperature (SSM/T) Sounder and a water vapor sounding system called SSM/T-2. The SSM/T and SSM/T-2 functions are assumed to be subsumed by the AMSU in later discussions in this paper.

D. GEOS-3, SEASAT, NIMBUS-7, AND SIR

The ATN and DMSP satellites contribute to the understanding of the two fluid media that dominate man's existence, the atmosphere and the hydrosphere, but more to the former than the latter. The hydrosphere, particularly the ocean, has been the subject of a number of experimental NASA missions. These missions have provided the foundation for several planned missions that will be discussed in the next section; they are also a part of the direct heritage of the instrument complement proposed later for the polar platform.

The Geodynamics Experimental Ocean Satellite (GOES-3) mission was based upon the Skylab radar altimeter experience and was the first satellite aimed specifically at oceanic measurements. With an altimetric precision of 30 to 40 cm, it provided the first clear view of the potential of altimetric measurements (ref. 5). It prepared the community for the 5 to 8 cm precision provided by the Seasat altimeter. Radar altimetry of the ocean provides data on the shape of the marine geoid, subsurface features through gravity-induced surface variations, surface currents, significant wave height, and surface wind speed (but not direction) (ref. 6). Figure II-3 shows a line drawing of the Seasat spacecraft, and Table II-3 lists its principal characteristics and those of its instruments.

In addition to continuing the altimetric measurements of GEOS-3 at higher precision, Seasat also carried a SAR, a wind scatterometer called the Seasat-A Satellite Scatterometer (SASS), a Scanning Multichannel Microwave Radiometer (SMMR), and a Visible and Infrared Radiometer (VIRR).

The SAR provided imagery of the ocean with a spatial resolution of 25 m, showed deep ocean wave patterns and water-land interaction processes, and provided surface elevation contours for the Greenland and Antarctic ice sheets. The SASS provided measurements of ocean surface wind speed with an accuracy of 2 m/s over a range from 4 to more than 26 m/s. The SMMR, which

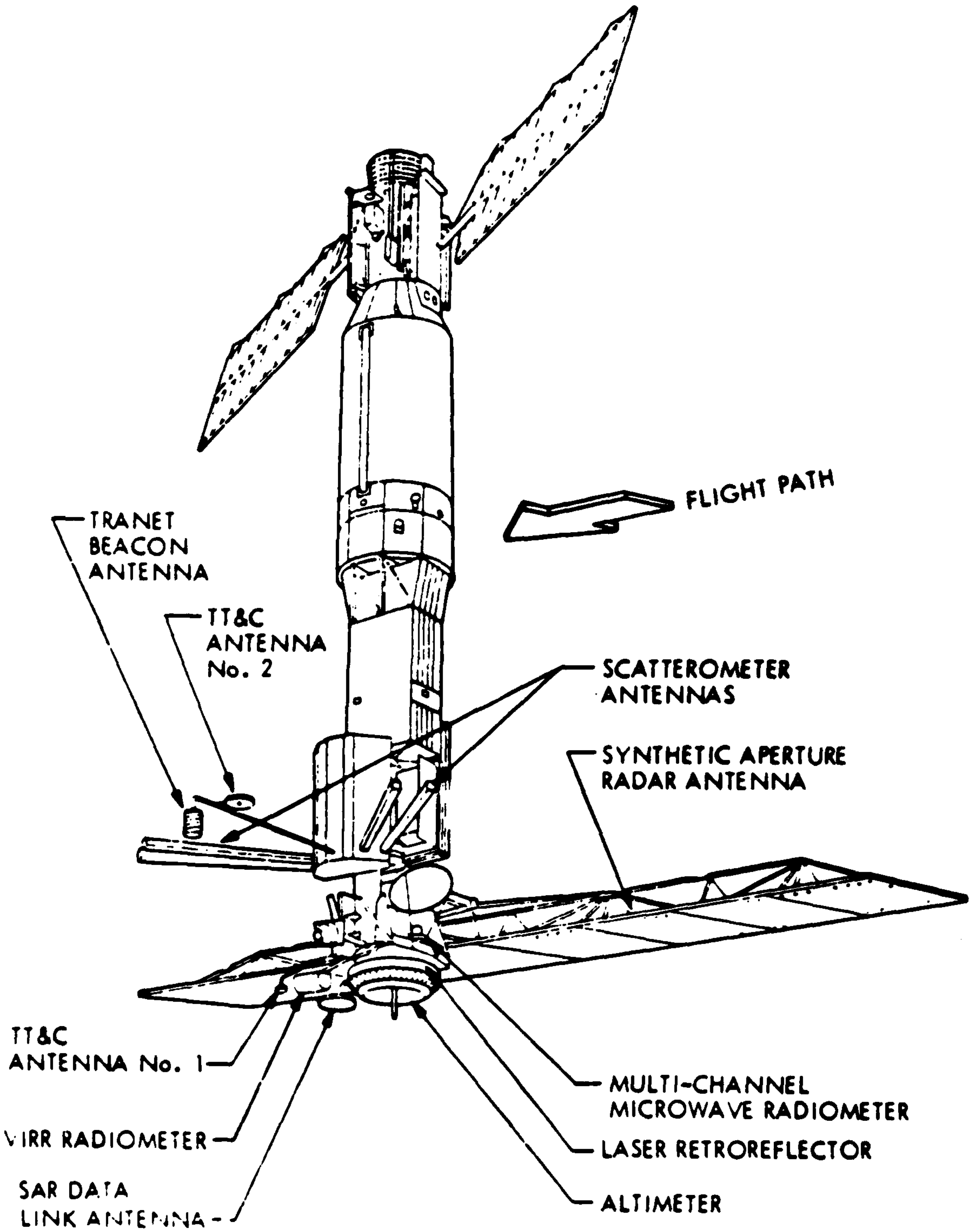

Figure II-3
Line Drawing of Seasat

Table II-3
Seasat-A Sensors

Sensor	Number of Channels/Frequencies	Spectral Range/ Frequency Range	Resolution	Swath Width	Power Requirements
ALT (Radar altimeter)	1	13.5 GHz	10 cm (wave height)	Nadir viewing	177 W
SASS (Scatterometer)	4	14.6 GHz	50 km	500 km (each side)	140 W
SMMR (Scanning Multichannel Microwave Radiometer)	5	6.6 to 37 GHz	16 x 25 km 87 x 144 km	900 km	60 W
VIRR (Visible and Infrared Radiometer)	2	0.40 to 12.5 μm	3 to 5 km	1,800 km	10 W
SAR (Synthetic Aperture Radar)	1	1,275 MHz	25 m	100 km	574 W

Sensor	Weight	Dimensions	Data Rate	Application
ALT	95 kg	1 m diameter (antenna)	8.5 kbps	Ocean topography
SASS	60 kg	—	2 kbps	Surface winds
SMMR	42 kg	—	2 kbps	Sea surface temperatures, sea ice, rainfall
VIRR	20 kg	—	12 kbps	Ocean temperatures, coastal features, cloud delineation, ice edge
SAR	128 kg	10.74 x 2.16 m (antenna)	120 Mbps	Ice topography

is also on the Nimbus-7 satellite, provides all-weather sea surface temperature measurements and monitors atmospheric water vapor. The SSM/I mentioned earlier under the discussion of the DMSP has enhanced characteristics over those of the SMMR. The VIRR provided supporting data to assist in the interpretation of the information gained from the other instruments.

The Nimbus-7 satellite carried a Coastal Zone Color Scanner (CZCS) in addition to the SMMR previously mentioned. The CZCS is a visible and infrared multispectral radiometer whose bands were chosen to correspond to strong organic absorption features or spectral regions where such features are absent. This permits the observation--after suitable analysis--of chlorophyll-a and phaeopigment-a concentrations and, hence, provides a measure of biological productivity. The successor to the CZCS, the Ocean Color Instrument, is suitable for a near-noon orbiting polar platform. Nimbus-7 also carried the predecessor instrument to the SBUV that will fly on NOAA F and G, and a Total Ozone Mapping Spectrometer (TOMS). Figure II-4 shows a line drawing of Nimbus-7, and Table II-4 provides a listing of the satellite parameters and those of its instruments.

The unique suite of instruments flown on Seasat and Nimbus-7 led to the extensive planning conducted for the National Oceanic Satellite System (NOSS), which in turn led to the N-ROSS satellite that is being developed jointly by the U.S. Navy and NASA*. The SASS would flow from Seasat, to N-ROSS and Radarsat, to the polar platform. The functions provided by the SMMR and the VIRR will be met by other instruments. The Seasat SAR also led to the Canadian plans for a Radarsat later this decade (ref. 7), and the European Space Agency's (ESA) ERS-1 satellite that will include a scatterometer and a SAR in the same instrument (ref. 8). More will be said of these two satellites in the next section.

NASA also has carried out a number of experiments using instruments in the space shuttle's payload bay. Among them are the two Shuttle Imaging Radar (SIR) experiments. Using technology quite similar to that of Seasat, they have continued measurements that were interrupted by the brief lifetime of the Seasat mission. Some of the most striking results have been obtained in arid regions where the radar pulses have shown an unexpected ability to penetrate the dry surface layers and expose geologic features beneath them. It is also evident that radars that are optimized for measurement of

*Further, Seasat begot the Navy's Geosat and NASA's proposed TOPEX satellites.

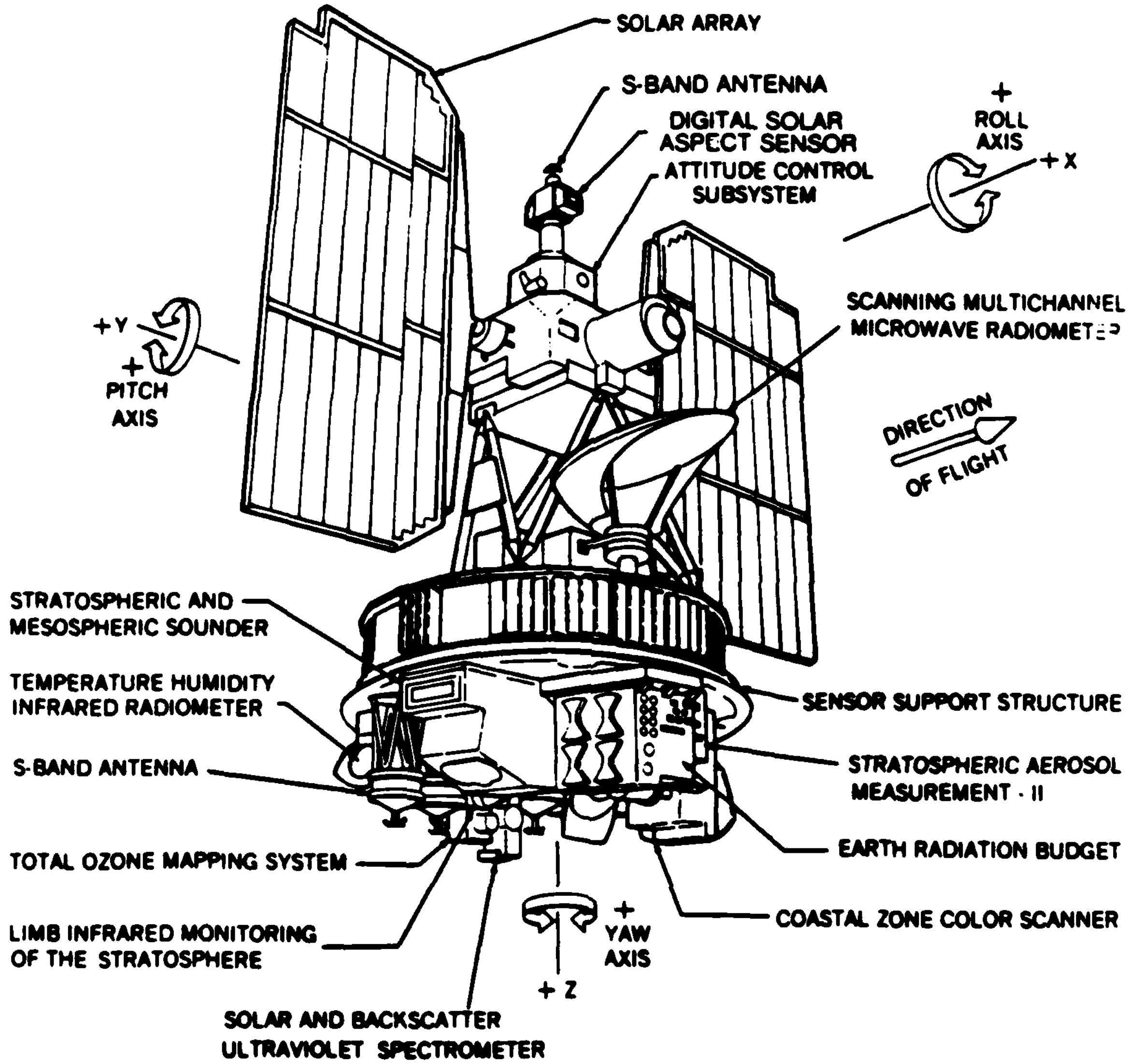

Figure II-4
Line Drawing of Nimbus-7

Table II-4
Nimbus-7 Sensors

Sensor	Number of Channels/Frequencies	Spectral Range/ Frequency Range	Resolution	Swath Width	Power Requirements
THIR (Temperature-Humidity Infrared Radiometer	2	IR	6.7 to 20 km	2,610 km	8.5 W
CZCS (Coastal Zone Color Scanner)	6	Vis/IR	0.825 km	1,566 km	11.4 W
SMMR (Scanning Multichannel Microwave Radiometer)	5	Microwave (6.6 to 37 GHz)	30 to 97.5 km	900 km	61.6 W
ERBI (Earth Radiation Budget Instrument)	22	0.2 to 50 μm	150 km	—	36.3 W
LIMS (Limb Infrared Monitor of the Stratosphere)	6	6.4 to 14.9 μm	1.8 x 18 km -3.6 x 28 km	NA	24.5 W
SAMS (Stratospheric and Mesospheric Sounder)	12	2.7 to 100 μm	—	NA	23 W
SAM II (Stratospheric and Aerosol Measurement II)	1	0.98 to 1.02 μm	—	NA	0.8 W
SBUV/TOMS (Solar Backscatter Ultraviolet Radiometer and Total Ozone Mapping Spectrometer)	12 (SBUV) 6 (TOMS)	160 to 400 nm (SBUV) 312 to 380 nm (TOMS)	— —	200 km	20 W

Table II-4 (concluded)
Nimbus-7 Sensors

Sensor	Weight	Dimensions	Data Rate	Application
THIR	9.1 kg	0.19 x 0.18 x 0.40 m 0.18 x 0.17 x 0.15 m	25 kbps	Moisture content of upper troposphere and stratosphere
CZCS	41.9 kg	0.78 x 0.53 x 0.37 m	800 kbps	Map ocean chlorophyll concentrations
SMMR	53.3 kg	Two 0.15 x 0.33 x 0.20 m modules One 0.15 x 0.17 x 0.20 m modules One antenna, 0.80 m diameter	2 kbps	Sea surface temperature, near-surface winds, sea ice, snow, rainfall, soil moisture
ERB	32.7 kg	0.33 x 0.36 x 0.48 m	450 bps	Earth Radiation Budget on synoptic and planetary scales
LIMS	67.3 kg	—	4 kbps	Vertical distribution of temperature and O_3, NO_2, HNO_3, and H_2O from lower stratosphere to lower mesosphere
SAMS	60.6 kg	—	150 bps	Vertical distribution of temperature and CO_2, H_2O, N_2O, CH_4, CO, and NO in the stratosphere and mesosphere
SAM II	17 kg	0.36 x 0.20 x 0.51 m	700 bps	Vertical distribution of stratospheric aerosols in polar regions
SBUV/TOMS	89.1 kg	0.36 x 0.26 x 0.56 m 0.33 x 0.20 x 0.15 m	650 bps	Vertical distribution of ozone, incident solar ultraviolet irradiance and back-scattered ultraviolet

ocean phenomena are not necessarily optimized to measure land phenomena. For this reason, later paragraphs of this chapter will distinguish between the radars called SEASAR and GEOSAR, for ocean and land, respectively.

The Navy has continued its interest in Seasat-type altimetry through an altimeter-only satellite, designated Geosat, that has improved capability over Seasat. The heritage of the altimeter is the longest of all oceanic sensors, from Skylab to GOES-3, Seasat, Geosat, N-ROSS, and TOPEX, to the polar platform.

E. GEOSAT, N-ROSS, ERS-1, TOPEX, AND RADARSAT

Seasat and other missions have given rise to the Navy's Geosat and N-ROSS, and ESA's ERS-1. These three missions are important not only from the perspective of the measurements they will make but also because of the way they illustrate the value of cooperation.

The N-ROSS satellite will carry a scatterometer for sea surface wind and wave velocities, an altimeter for significant wave height and other parameters, a microwave radiometer for sea surface temperature measurements, and an SSM/I for all-weather sea ice and other measurements (ref. 9). Figure II-5 shows an artist's concept of N-ROSS, and Table II-5 gives a listing of the planned instrument characteristics. An important aspect of the mission is the nominal 2-day repeat cycle for measurements.

The ERS-1 carries an Advanced Microwave Instrument (AMI) that includes the functions of a SAR and a scatterometer. The satellite also carries an altimeter and an infrared Along-Track Scanning Radiometer (ATSR). ERS-1 also has a nominal 2-day repeat cycle. Figure II-6 shows a line drawing of the planned configuration of the satellite, and Table II-6 lists the characteristics of the satellite and its payload.

If the parameters of N-ROSS and ERS-1 are properly coordinated, the nominal 2-day repeat cycle of the satellites is converted to daily global ocean coverage. This is of major significance to the preparation of nowcasts and forecasts to support the maritime community. It should be noted that such coordination does not impact national objectives or the cost of the missions, but it dramatically increases their value. The availability of wide swath width SSM/I data from both N-ROSS and the DMSP system provides a further positive linkage between the two systems that also greatly enhances the data set. It is expected that the success of these missions will create a strong demand from the maritime community for a continuation of these data. This demand can lead to the

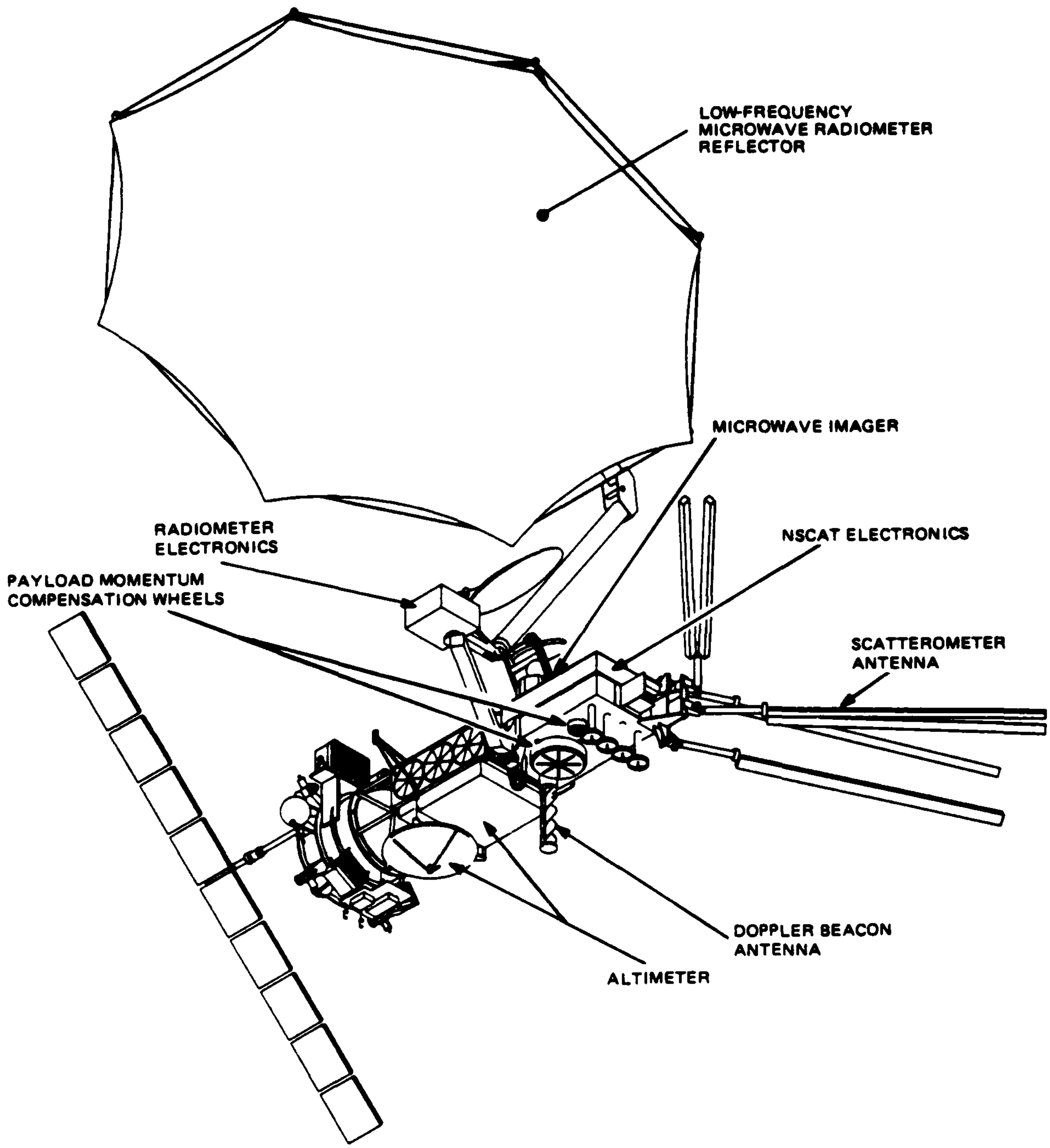

Figure II-5
Line Drawing of N-ROSS

Table II-5
N-ROSS Sensors

Sensor	Number of Channels/Frequencies	Spectral Range/ Frequency Range	Resolution	Swath Width	Power Requirements
RA (Radar Altimeter)	1	13.5 GHz	3.5 cm (wave height)	Nadir view only	113 W
SSM/I (Special Sensor Microwave Imaging)	4	19.3 to 85.5 GHz	25 km	1,394 km	36 W
SCATT (Scatterometer)	4	13.995 GHz	25 km (each side)	600 km	240 W
LFMR (Low-Frequency Microwave Radiometer)	2	5.2 to 10.4 GHz	2.5 km	1,400 km	50 W

Sensor	Weight	Dimensions	Data Rate	Application
RA	90.9 kg	0.50 x 0.34 x 0.25 m	8 kbps	Sea surface topography
SSM/I	55 kg	0.66 m (antenna diameter)	3.6 kbps	All-weather sea surface temperatures, ice edge, precipitation
SCATT	147 kg	3.10 x 0.10 x 0.15 m (x 6) 1.15 x 0.55 x 0.31 m	2 kbps	Sea surface winds
LFMR	56.8 kg	5.9 m (antenna diameter)	14 kbps	Sea surface temperature (high resolution)

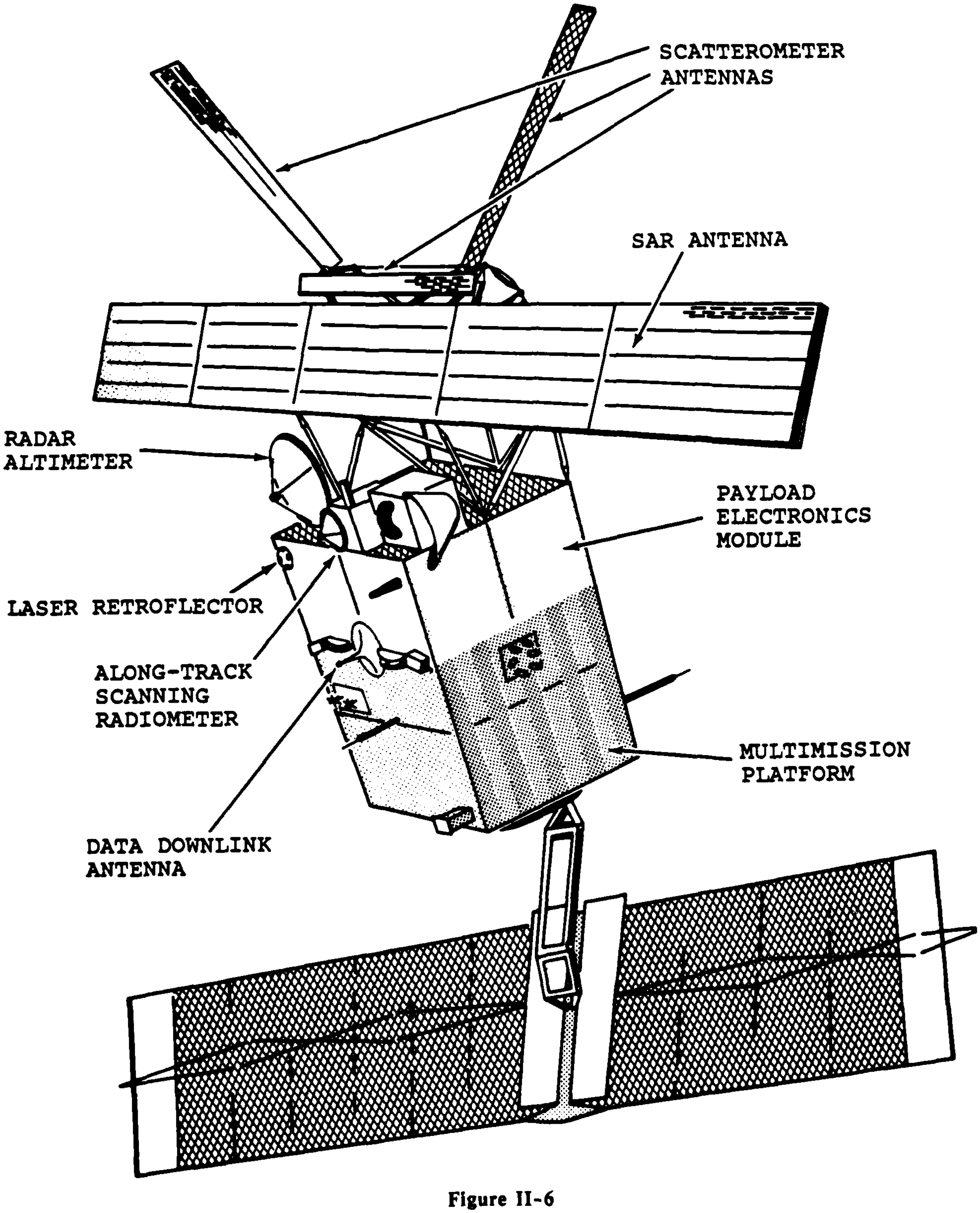

Figure II-6
Line Drawing of ERS-1

Table II-6
ERS-1 Sensors

Sensor	Number of Channels/Frequencies	Spectral Range/ Frequency Range	Resolution	Swath Width	Power Requirements
AMI[a] - SAR[b] mode	1	5.3 GHz	30 m	100 km	300 W
AMI - wind mode	1	5.3 GHz	50 km		54 W
Radar altimeter	1	13.5 GHz	0.5 m (wave height)	Nadir viewing	50 W
ATSR[c] - M radiometer	3	3.7 to 12 μm	1 km	500 km	48 W
ATSR - M sounder	3	23.8 to 36.5 GHz	22 km	500 km	30 W

Sensor	Weight	Dimensions	Data Rate	Application
AMI - SAR mode	—	10 m x 1 m (antenna)	100 Mbps	Ice topography, geologic structures
AMI - wind mode	—	2.5 m x 3.6 m (antenna)	15 Mbps	Surface winds
Radar altimeter	—	1.2 m (antenna diameter)	—	Sea surface topography
ATSR - M radiometer	33 kg	—	205 kbps	Sea surface temperature
ATSR - M sounder	21.5 kg	—	205 kbps	Atmospheric profiles

a Active Microwave Instrument
b Synthetic Aperture Radar
c Along-Track Scanning Radiometer

incorporation of the instruments from N-ROSS and ERS-1 on the polar platform.

N-ROSS and ERS-1 are not the only ocean-related missions under study. NASA is planning a dedicated altimeter mission, Ocean Topography Experiment (TOPEX) satellite, specifically designed to determine the ocean circulation. It will have an improved altimeter (2 cm precision) and a unique orbit (63 degree inclination and 1,300 km altitude) to enhance accurate tracking and determination of the global tides. An experimental Global Positioning System (GPS) planned to give sub- decimeter tracking accuracy is proposed to be carried aboard. Given a successful mission, it will then be possible to continue TOPEX-quality observations of ocean circulation by using a similar altimeter and GPS tracking package, but aboard a platform of opportunity--even one in a sun-synchronous orbit.

Canada is currently evaluating a mission called Radar Satellite (Radarsat). This mission is targeted at four sets of applications of a SAR: operations in sea-ice covered waters, basic oceanography, renewable resource assessments, and detection of nonrenewable resources. Combined with ERS-1, it will further SIR flights on the space shuttle. A Japanese mission called Japan Earth Resources Satellite (JERS-1) will provide ample experimentation to justify the continuation of SAR missions, both SEASAR and GEOSAR, on an operational basis.

F. LAND SATELLITE SYSTEMS

The systematic observation of the land masses of the Earth from space began with NASA's Earth Resources Technology Satellite (ERTS), which became the Land Satellite, commonly known as Landsat. Some sporadic coverage was provided by the manned missions before that time. Through the 1970's, the Multispectral Scanner (MSS) and the Return Beam Vidicon (RBV) camera were the principal sensors employed for this purpose. The MSS system proved more valuable through research than the RBV system and became the principal Landsat sensor. This was augmented in the early 1980's by the Thematic Mapper (TM) on Landsat-4 and -5 (ref. 10). Figure II-7(a) shows a line drawing of Landsat-1, Figure II-7(b) shows a line drawing of Landsat-4, and Table II-7 provides a summary of the characteristics of their sensors.

Scheduled for the mid-1980's is the French Systeme Probatoire d'Observation de la Terre (SPOT) system, which has characteristics that complement those of Landsat-4 and -5. SPOT has fewer spectral bands but higher spatial resolution than Landsat, and it provides offset pointing and stereo capability. Figure II-8 shows a line drawing of SPOT, and Table II-8 describes its sensor characteristics.

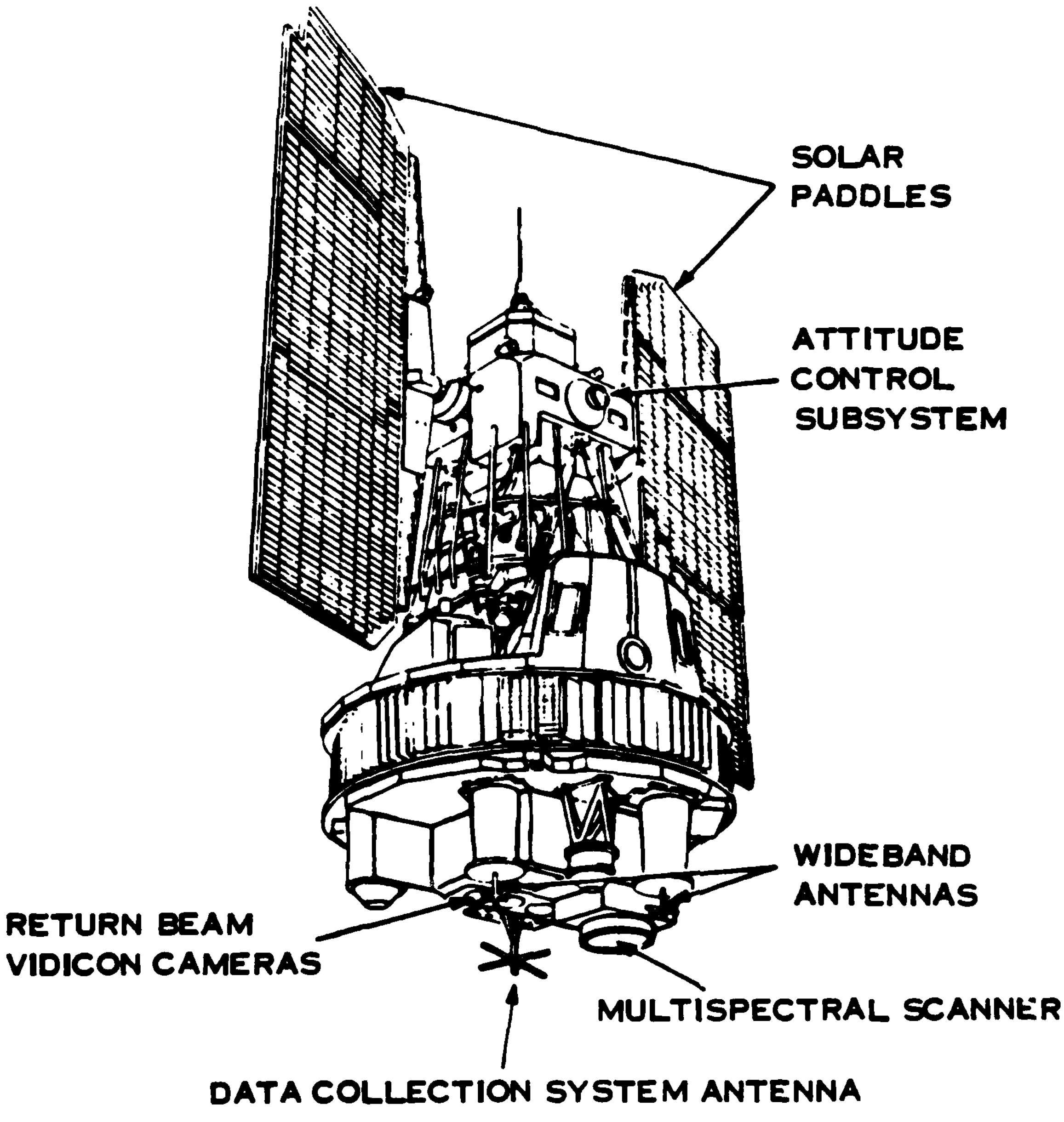

Figure II-7(a)
Line Drawing of Landsat-1

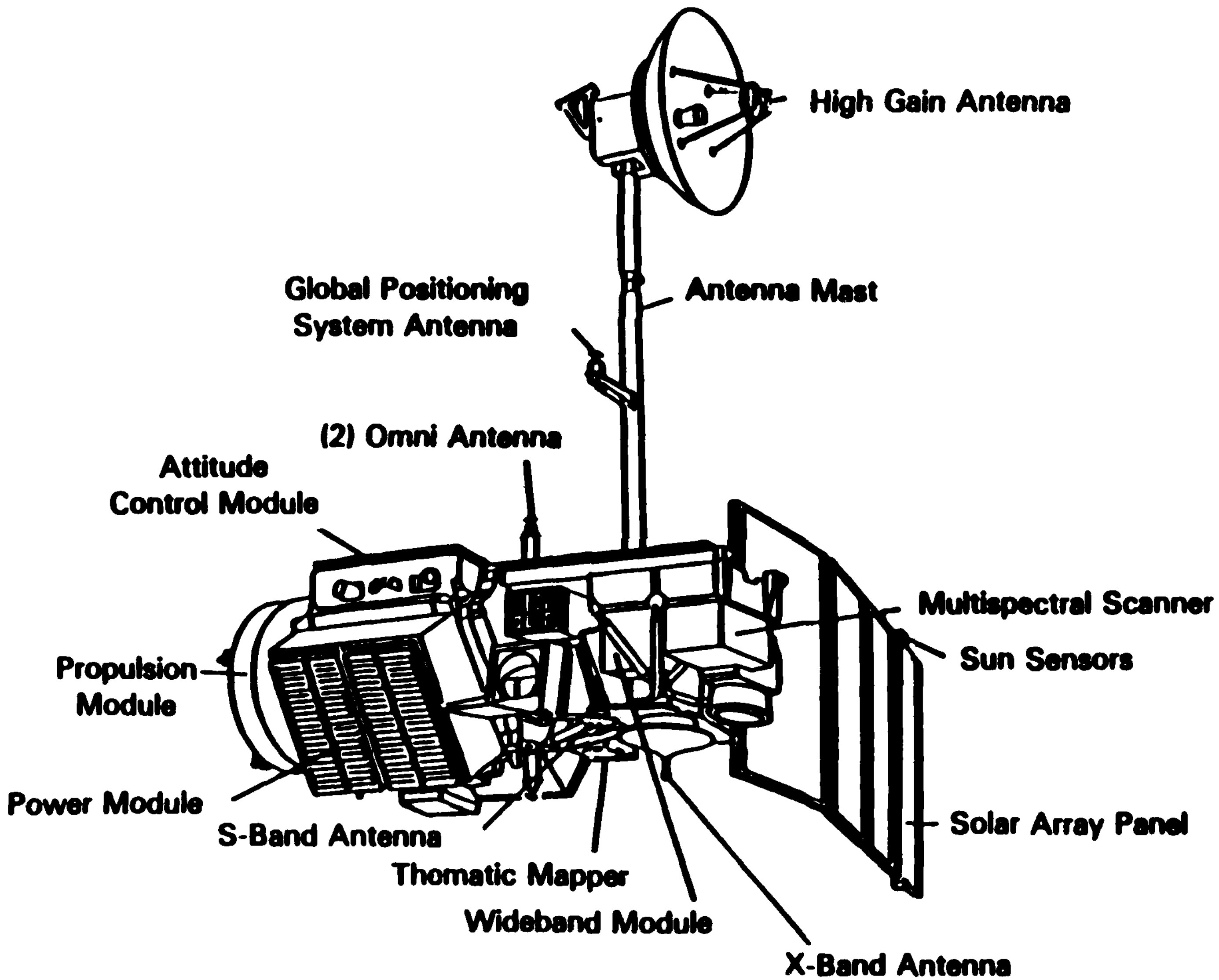

Figure II-7(b)
Line Drawing of Landsat-4

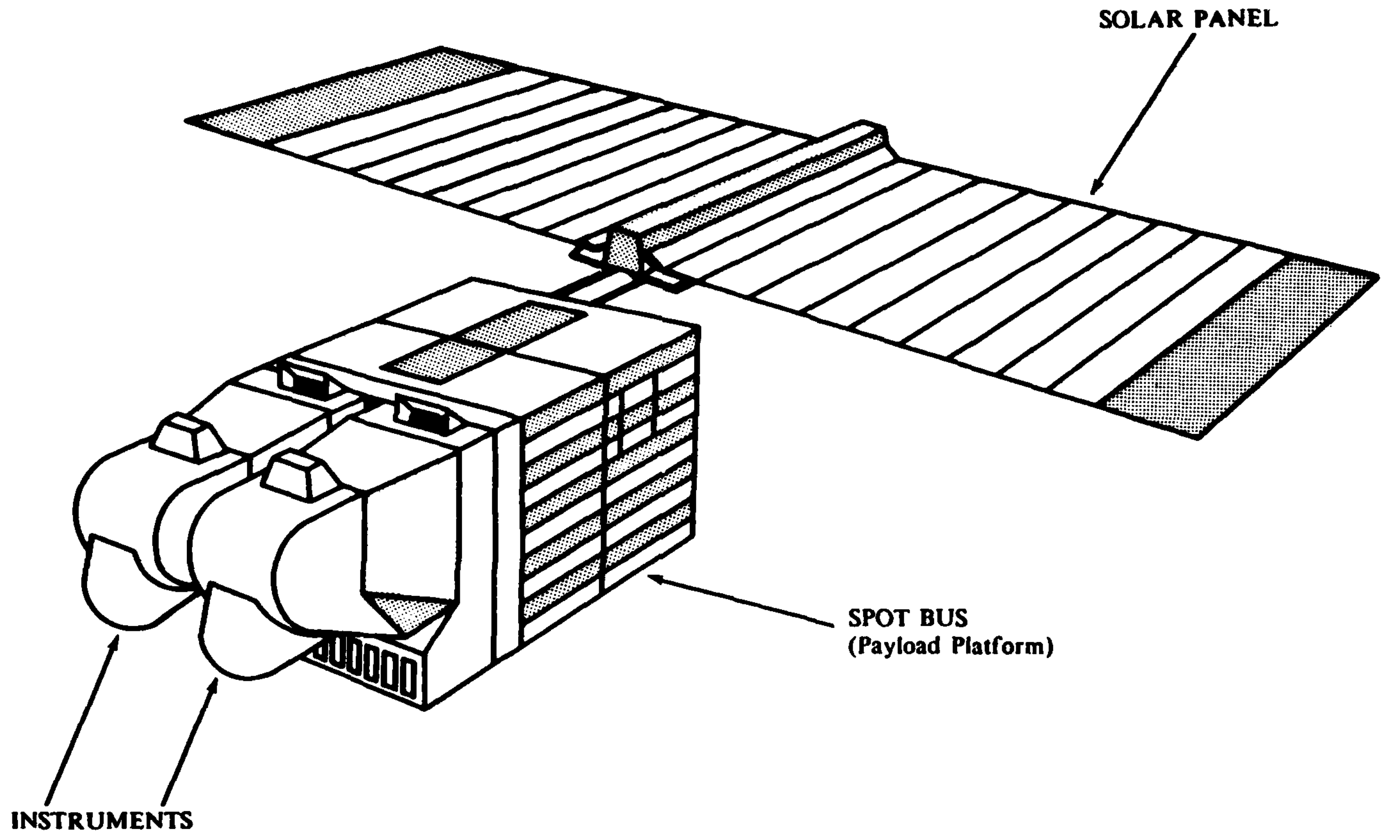

Figure II-8
Line Drawing of SPOT

Table II-7
Landsat Sensors

Sensor	Number of Channels/Frequencies	Spectral Range/ Frequency Range	Resolution	Swath Width	Power Requirements
RBV[a] (Return Beam Vidicon)	1	0.5 to 0.75 μm	40 m	185 km	174 W
MSS[b] (Multispectral Scanner)	4	0.5 to 1.1 μm	80 m	185 km	82 W
TM[c] (Thematic Mapper)	7	0.45 to 2.35 μm (6 channels) 10.4 to 12.5 μm (1 channel)	30 m 120 m	185 km	300 W

Sensor	Weight	Dimensions	Data Rate	Application
RBV[a]	92.3 kg	0.54 x 0.26 x 0.78 x 3 m 0.15 x 0.15 x 0.2 m 0.15 x 0.15 x 0.25 m	6.4 Mbps	Land use, urban planning, mapping, agriculture, forestry, water resources, geology, mineral resources
MSS[b]	66.1 kg	0.17 x 0.15 x 0.10 m 0.59 x 1.26 x 0.54 m	15.06 Mbps	Same as above
TM[c]	245.9 kg	1.1 x 0.7 x 2.5 m	84.9 Mbps	Same as above

a On Landsat-1 through -3 (with slight variations between satellites)

b On Landsat-1 through -5 (with slight variations between satellites)

c On Landsat-4 through -5

Table II-8
SPOT Sensor

Sensor	Number of Channels/Frequencies	Spectral Range/ Frequency Range	Resolution	Swath Width	Power Requirements
HRV (High-resolution visible range instrument)	4	0.50 to 0.89 μm	10 m	60 km	115 W
					1,200 W*

Sensor	Weight	Dimensions	Data Rate	Application
HRV	170 kg	2.26 x 1.5 x 1 m	50 Mbps	Land use, urban planning, mapping, agriculture, forestry, water resources, and geology
	650 kg*	--		

* Entire payload (including two HRVs)

One of the potential life-limiting mechanisms for the MSS/TM class of sensor is the large, mechanically moving mirror that produces the scan perpendicular to the orbit track, i.e., the cross-track scan. Research and development activities have been directed at the production of an all solid-state sensing device called the Multispectral Linear Array (MLA) or "push-broom" line scanner (ref. 11). It is anticipated that this technology will eventually become the standard for multispectral imaging devices. The flexible type of imaging instrument that would benefit from flight on a polar platform would almost certainly be of the MLA class.

The land-sensing system could be a major beneficiary of the availability of an astronaut-tended platform in polar orbit. The economics of the Landsat system were the subject of a long controversy that has extended to the utility and value of future systems, both governmental and private. If the cost of placing a sensor on an existing platform and maintaining it through in-orbit servicing were dramatically less expensive than launching and maintaining a dedicated satellite in orbit, the economic analysis of land-sensing systems would shift in a very favorable direction.

G. POLAR PLATFORM OPERATIONAL PAYLOAD SELECTION--BASIC PRINCIPLES

The cascading of all the aforementioned missions to create a consensus payload for a polar platform is shown in Figure II-9. This figure is a duplicate of Figure II-1, but with notations added to show the aggregation of instruments from the individual missions to the platform.

The easiest first step by which a payload could be selected for the polar platform is to divide the operational remote-sensing function into three segments: atmosphere and meteorology, oceans and ice, and land. In each segment it is possible to make a brief statement about what is to be measured and over what time scale. One cautionary note is in order. The separation of the remote-sensing function into segments is convenient, but highly artificial. There is great and necessary synergism among the atmospheric and oceanographic instruments, and their coordinated use will lead to striking new insights into ocean-atmosphere processes.

1. Atmosphere and Meteorology

The principal functions to be performed involve providing quantitative data for numerical weather prediction, quantitative and qualitative imagery data for local readout, environmental data collection from in situ sensors, and measurements related to climatic change. Under the present two-polar

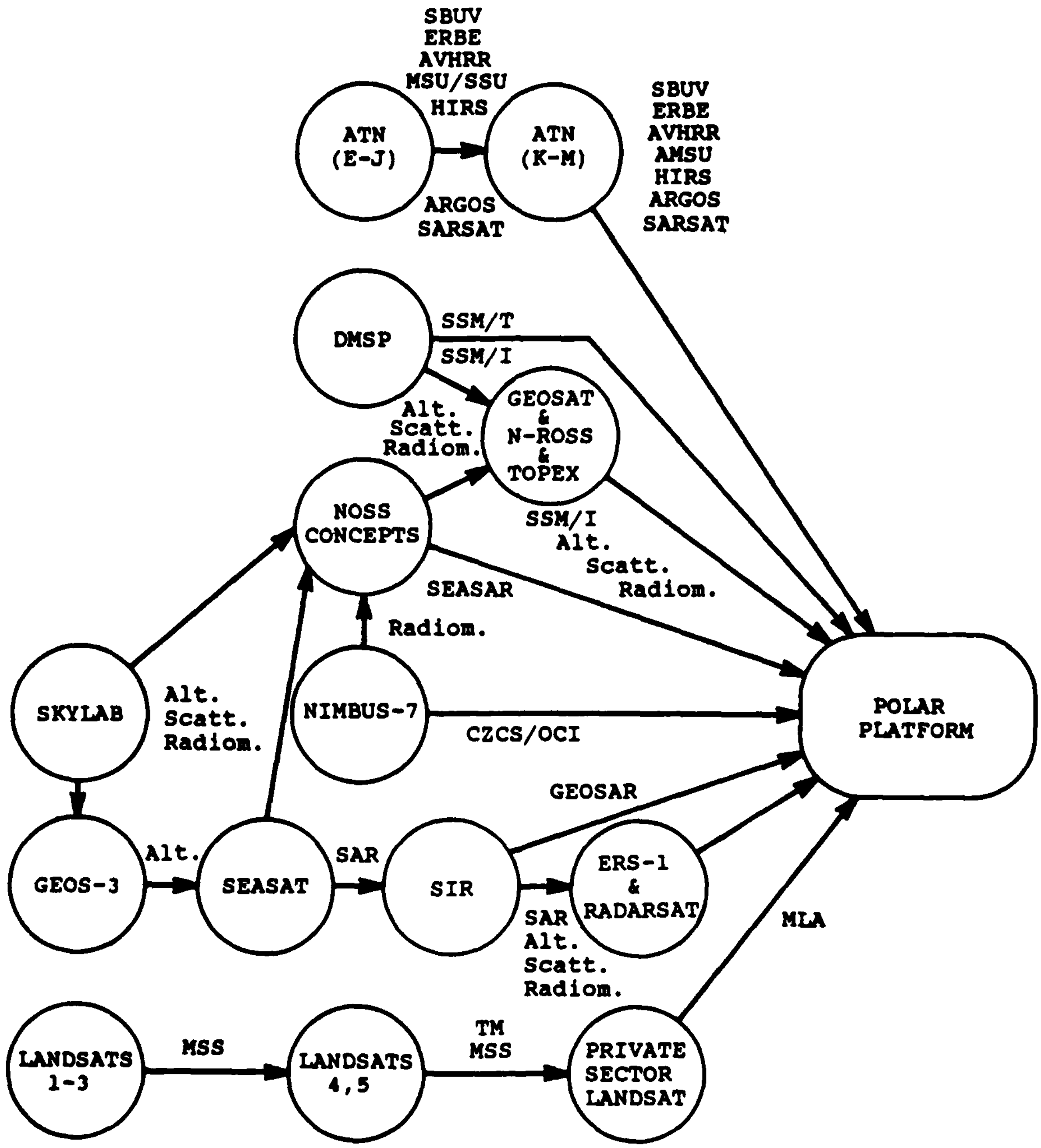

Figure II-9
Flow of Instruments to Polar Platform

system, data are assembled for computer analysis twice daily. These analyses include data from radiosondes, surface observations, and satellite measurements. The fundamental physical problem is the measurement and analysis of a changing fluid medium on a frequent enough time scale to predict its future behavior. It is self-evident that continuing daily measurements are required. The payloads devised for the ATN and DMSP satellites have been tailored to achieve this goal and, with appropriate merger of some instrument functions, can be transferred directly to the polar platform.

It is apparent that a single polar platform is not adequate to achieve the required frequency of observation needed to characterize the medium. Instead, at least two are required, with their Equator crossing times generally chosen to meet the requirements of the nominal twice daily runs of synoptic weather models. There is some flexibility in setting the exact Equator crossing times that is a function of ground data processing system capability. Therefore, the needs of users of data in the other two categories can effectively influence the ultimate choice of an Equator crossing time over a reasonable range.

2. Oceans and Cryosphere (Ice)

The remarks made about the atmosphere and meteorology apply to oceanic and ice measurements as well. Again, a changing fluid medium must be measured frequently enough to characterize its present condition and predict its future behavior. This frequency of observation can be attained by placing oceanographic instrumentation on the two polar platforms.

One slight distinction is that the high data rate associated with a SEASAR system and its use in observing ice floes, which are relatively slow moving in comparison to other atmospheric or oceanic phenomena, may militate toward placing that instrument on only one of the two platforms. The GEOSAR would occupy the equivalent position on the other platform. The remaining instrumentation will consist of a scatterometer, altimeter, microwave imager and radiometer, and an Ocean Color Instrument--the latter, because it requires a high sun angle, only being on a near-noon orbit, perhaps at 1 p.m. The SEASAR and the OCI will fly on the same satellite to permit correlative measurements. Thus, the basic oceanographic instrumentation suite will be that of ERS-1 with a microwave radiometer augmenting the ATSR and the addition of an OCI and SSM/I type sensor. Alternatively, the instrumentation can be characterized as that of the N-ROSS with the addition of a SAR and an OCI.

The effect of the oceanographic instrument suite on the two

platforms is the daily provision to the maritime community of a global measurement of significant wave height, ocean currents, sea ice, surface winds and waves, and ocean color. Long-term integrated data sets on other parameters such as ice sheets, ocean circulation systems, energy flux, ocean transport mechanisms, biological production, and carbon dioxide ocean/atmosphere relationships will, for the first time, be obtained on a routine basis.

3. Land

The land measurements will be made principally with two instruments, MLA and GEOSAR. Unlike the daily global coverage requirements of the meteorological and oceanographic instruments (less the SEASAR), the more limited swath widths of the land instruments will limit their repeat coverage of a given spot--in the absence of off-nadir pointing--to a nominal 16 to 18 days. On the assumption of 50-percent average cloud cover, the MLA will provide only monthly coverage of a given spot. The MLA will require a morning orbit, and the GEOSAR will share space on that platform to permit correlative observations with the MLA. Off-nadir pointing is a likely capability to be included in the MLA to permit more frequent revisits of chosen areas. Again, the high data rate associated with the instrument, and the relatively slowly changing phenomena it observes, lead to the conclusion that only one GEOSAR is needed in orbit at a given time.

The high spatial resolution measurements of the MLA system, which have only a coarse temporal resolution, will be complemented by land data derived from the medium resolution, but high temporal resolution, meteorological imager and radiometer that will evolve from the current AVHRR.

4. Other Payloads

Two of the auxiliary payloads--the Argos data collection and platform location system and the SARSAT system--require timely revisits to all parts of the Earth and, therefore, would be carried on both polar platforms. The third auxiliary instrument, the Space Environment Monitor (SEM), will also be carried on both platforms.

From the discussion of past missions and their instruments, and this rudimentary review of observational requirements, it is possible to prepare a strawman payload for a two polar platform system. A more complete listing of mission payloads is given in Appendix A, where Table A-1 lists the instruments that have flown in the past, are on present satellites, or are planned for future satellites.

H. POTENTIAL POLAR PLATFORM OPERATIONAL INSTRUMENT COMPLEMENT

At this point, it is appropriate to consider in more detail the operational instrument complement that will have reached an adequate state of development for inclusion on the polar platform. Adequate state of development is defined by three criteria: 1) completion of development work on the space hardware, 2) completion, where necessary, of flight testing on the space hardware, and 3) readiness of the applications community to employ the data regularly. It is assumed--rather arbitrarily--that the manned segment of the Space Station will fly first in 1992 and be followed shortly thereafter by the polar platform, perhaps in 1994, although this date is later than current NASA planning dates. This implies that the manufacture of the instruments would start in 1990, and that flight readiness would have been adequately established by that date. For some instruments, that date could be expedited considerably. Indeed, most instruments could begin during the next year.

The sensor payload will be categorized first by discipline (atmosphere and meteorology, oceans and cryosphere, and land), while within each discipline the following instrument categories will be employed:

- Radiometers and imagers (visible, infrared, and microwave)
- Sounders (infrared and microwave)
- Active sensors (altimeters, scatterometers, and SAR)

The auxiliary instruments (space environment monitor, data collection and platform location systems, and search and rescue transponders and processors) will be included on both platforms, as noted in the preceding section.

1. Atmosphere and Meteorology

The objective of the sensors in this discipline category is to continue the measurements being carried out currently by the ATN spacecraft, with reasonable capability enhancements. Revolutionary increases in instrument capability are not forecast, but revolutionary utilization of data is.

a. Radiometers and Imagers. There will be a continuing requirement for a medium-resolution imaging radiometer (MRIR) operating in the visible and infrared. The instrument will be a successor to the AVHRR flown on the NOAA K through M series of polar orbiters. Normal progress in the user community will lead to improving the spatial resolution from the current value of 1 km to a smaller value of 500 m. The applications

of this sensor point out the basis for the cautionary note given about the dangers in using discipline categories, because they span all of the three categories used here. The applications include:

- Weather forecasting (particularly in remote areas and the developing world)
- Precipitation estimation
- Global radiation balance studies
- Ice, snow, and frost mapping
- Sea surface temperature and ocean current boundary mapping (in the absence of clouds)
- Monitoring of hydrologic events
- Vegetation assessments
- Continuation of the worldwide provision of Direct Sounder Broadcast (DSB), Automatic Picture Transmission (APT), and High-Resolution Picture Transmission (HRPT) services.

The principal characteristics of the measurements provided by this sensor are daily global coverage, precise radiometric calibration, and multispectral coverage extending from the visible to the far infrared. The six-band AVHRR system with up to 10-bit quantization per band for the NOAA K to M series will be expanded to as many as 10 bands for the polar platform. The sensor will be placed on both the morning and afternoon polar platforms. For conceptual design purposes, the parameters given for the AVHRR in Table II-2 can be employed to assist in scoping the payload requirements for a platform.

In the climate-related area there are two instruments, a global ozone measuring device and an Earth radiation budget radiometer. The Solar Backscatter Ultraviolet (SBUV) instrument was flown on Nimbus-7, and will also be flown on the ATN series into the early 1990's. The device provides data from which global maps of ozone concentration are made. From these maps, long-term ozone trends are estimated. It measures backscattered solar radiation in an 11.3 degree field of view in the nadir direction in 12 discrete, 1.1 nm wide bands that are between 252 and 339.8 nm. The instrument proposed for the polar platform would be a follow-on instrument to the SBUV. Canada has expressed an interest in providing this device. For planning purposes, the general characteristics of the SBUV given in Tables II-1 and II-4 are used. It is referred to

below as a Global Ozone Monitoring Radiometer (GOMR). Similarly, the ERBE can be used as the model for the second instrument. The SBUV requires a high sun angle and would not, therefore, be flown on an orbit with an early morning crossing time.

b. Sounders. The sounding system on the present series of NOAA polar orbiters (NOAA E through J) consists of the MSU and the SSU and HIRS sensors mentioned previously. This complement is called the TIROS Operational Vertical Sounder (TOVS). The NOAA K through M satellites will have the MSU and SSU sensors replaced by the AMSU. The new vertical sounder system will provide:

- Better definition and resolution of the temperature sounding below cloud cover
- The capability to identify and quantify precipitation
- Improved atmospheric water vapor measurements
- An indication of soil moisture and snow thickness

The HIRS sensor will continue as an adjunct to the AMSU because it provides improved temperature soundings in the lower troposphere in clear air, is used for long-wave Earth radiation balance measurements, and is used to cross-calibrate the AMSU measurements.

The overall purpose of the new sounder system is to contribute twice-daily measurements to the numerical forecast models. In the 1990's, these models will require a measurement spacing between soundings of 10 to 50 km for regional models, 150 km for global models, and 250 km for global climate studies. These resolutions are accommodated by the AMSU/HIRS combination. The parameters of that combination, given in Table II-2, are used for initial planning purposes for a polar platform. The sounder system will be designated the advanced TOVS or, simply, the ATOVS.

c. Active Sensors. It is not anticipated that active sensors will be available for atmospheric measurements during the initial deployment of a polar platform. The active sensors flown for oceanographic purposes will provide surface wind speed and direction, sea ice information, and numerous experimental studies for improved operational capability. One candidate for later flight is a coherent infrared laser radar system--usually called Windsat--that is intended to measure the global tropospheric wind field with a horizontal resolution of 1 km (ref. 12).

2. Oceans and Cryosphere (Ice)

The objective of the sensors in this discipline category is to produce a timely, globally synoptic view of the world's oceans and ice fields, and to provide mesoscale analyses of areas of special importance, e.g., the extended economic zone. They will continue the measurements carried out in the latter half of the 1980's by such spacecraft as NOAA K, L, and M, N-ROSS, TOPEX, Geosat, ERS-1, Radarsat, JERS-1, and MOS-1.

The representative benefits and improvements in ocean activities that will result from this suite of instruments will include, as outlined by Hussey (ref. 13):

- Improvement of sea surface temperature and water mass analyses that will aid in the location of productive fishing areas

- Improvement in location of thermal currents and eddies, which will aid in the routing of ships and forecasting the movement of oil spills

- Improvement in ocean wave analyses and forecasts, which will assist in vessel routing and will provide better information for offshore oil and gas platform operations and construction projects

- Improvement in sea ice boundary analyses, which will aid fishing operations near the ice edge

- Improvement in sea ice concentration analyses and forecasts, which will improve polar ship routing and the utilization of ice breaker capabilities

- Improvement in water mass definition; routine measurements of chlorophyll aid in the tracing of ocean mesoscale and circulation features

- Improvement of fishery management capabilities through near-real-time measurements of chlorophyll and sea surface temperature

- Improvement of numerical weather forecasting; all-weather sea surface winds and temperatures will improve the definition of the baseline conditions from which numerical forecasts are made

- Improvement in inputs to the National and World Climate Research Programs through global scale ocean measurements

- Improvement in the forecasting of severe storms through

the measurements of surface winds and temperatures underneath the extensive cover of storms at sea

The following paragraphs will discuss the specific instruments and their characteristics. The sounder category is included because no special sounding instruments, beyond those discussed in the preceding discipline category, are required for ocean and ice measurements.

a. Radiometers and Imagers. Three instruments are included in this category--the AMR, the SSM/I, and the OCI.

The AMR will be derived from the Low Frequency Microwave Radiometer (LFMR) of the N-ROSS mission and the earlier planning for the Large Antenna Multichannel Microwave Radiometer (LAMMR) of the proposed NOSS program (ref. 13). The AMR will have seven frequencies (4.3, 5.1, 6.6, 10.65, 18.7, 21.3, and 36.5 GHz) and will operate at both polarizations to produce 14 measurement channels. The 5 m-diameter offset parabolic antenna will rotate at 60 rpm, with a receiving field-of-view offset 43.6 degrees from nadir. It will produce sea surface temperature measurements with a 25 km spatial resolution and a 1.5 K temperature resolution over a 1,350 km swath width. Wind speed will be determined over a range of 0 to 50 m/s, with an accuracy of 2 m/s or 10 percent, whichever is greater at 17 km resolution. Sea ice concentration will be measured to within +15 percent at 9 km resolution and classified as new, first-year, or multiyear ice. The thickness will be estimated to within 2 μm. Atmospheric water vapor will be measured to within 0.2 g/cm^2 at 9 km resolution.

The AMR requires adequate space for the 5 m diameter antenna and protection from radio frequency interference. It also is rather heavy in comparison to most of the other instruments mentioned in this paper--350 kg. It will require 150 to 200 W of power. The nominal data rate for the sensor is 100 kbps (ref. 13).

It may be desirable to complement the precise all-weather sea surface temperature measurements of the AMR with the potentially very precise measurements of the Along-Track Scanning Radiometer that will be flown on ESA's ERS-1. This instrument uses an innovative scanning approach to derive an improved atmospheric correction, and offers the possibility of providing accuracies near 0.3 K (ref. 8).

The SSM/I is the same instrument previously mentioned. Because its characteristics have already been provided, no further discussion will be given here.

The OCI will be an improved version of the CZCS flown on the Nimbus-7 satellite. Plans currently are being developed to

fly the sensor on the NOAA K, L, and M series, whichever is the afternoon satellite. The improved CZCS will consist nominally of a nine-spectral-band instrument (eight channels in the visible and near-infrared wavelengths and one channel in the thermal infrared). It will employ a 500 m spatial resolution, and all nine detectors will view the same resolution element simultaneously. Measurements of chlorophyll will be made in the range of 0.05 to 100 mg/m^3 with an accuracy at least within a factor of 2. The diffuse attenuation coefficient, a measurement of sedimentary distributions, is measured over the range 0.01 to 6 μm^{-1} also with an accuracy of at least a factor of 2.

The general physical parameters given previously for the CZCS can be used for approximate sizing of the instrument and its support demands. A logical question is whether the OCI bands can be combined with those of the MRIR mentioned in the preceding discipline category. A preliminary assessment suggests that the signal-to-noise requirements differ radically between the two instruments. As a result of its scene lighting requirements, the OCI is adversely affected by sun glint effects to a greater extent than the MRIR, and may require offset pointing to ameliorate this factor. Further, the OCI system, if folded into the MRIR, would have very limited use on the morning polar platform, but would make the MRIR more complex. For these reasons, the most cost-effective approach appears to be building two tailored instruments rather than one general purpose instrument.

b. <u>Active Sensors</u>. Three active sensors will be included in the payload: an altimeter, a scatterometer, and the SEASAR. Their characteristics are outlined as follows.

The altimeter essentially will be a duplicate of that flown on the N-ROSS mission, which is itself a duplicate of the Geosat altimeter. The altimeter will provide 8 cm accuracy in the altitude measurement, significant wave height to an accuracy of 0.5 m, and wind speed to 2 m/s. The characteristics of the N-ROSS altimeter given in Table II-5 are used for initial planning purposes. An alternative approach is to use a TOPEX-quality altimeter, but that can be left to a later decision. The N-ROSS altimeter will meet all operational requirements currently perceived.

Similarly, the scatterometer will continue the measurements made by N-ROSS and use the same basic six-beam design. Again, the characteristics of the N-ROSS scatterometer, or NSCAT, are given in Table II-5.

The SEASAR will incorporate the advances in satellite synthetic aperture radar technology gained from missions beginning with Seasat in 1978 and culminating with SIR-D, anticipated to

fly on the space shuttle at the end of this decade. The Seasat SAR and SIR-A (1981) were both single frequency (L-band), horizontally polarized, and had fixed incidence angles when viewing the surface (20 degrees from vertical for Seasat and 50 degrees from vertical for SIR-A). SIR-B, launched in 1984, operates in L-band and is horizontally polarized, but its incidence angles are adjustable between 15 and 60 degrees. SIR-C, scheduled for launch in 1987, will be characterized by dual frequency, multiple polarization, and adjustable incidence angles SIR-D will have the additional capability of many frequencies (ref. 14).

Other planned satellite missions with SAR capabilities include Europe's ERS-1 (1988), which will operate in C-band and will have a fixed incidence angle of 20 degrees from vertical; Canada's Radarsat (1990), which also will operate in C-band but with adjustable incidence angles ranging from 20 to 45 degrees from vertical; and Japan's JERS-1 (1991), operating in L-band with a fixed 33-degree incidence angle. The SEASAR proposed for the polar platform will allow multiparameter observations similar to SIR-D, using combinations of frequencies, polarizations, and incidence angles that work best for ocean monitoring. Possible applications include observations of surface winds, wave structure, upwelling, currents, fronts, bottom morphology, oil slicks, entrained materials, and coastal refraction (ref. 15).

c. Land. The sensors in this discipline category will continue the comparatively high-resolution measurements carried out by the Landsat series, the shuttle-borne SIR series, and the instruments that will result from the current activities to create a private entity in civil land remote-sensing from space. Two sensors are discussed: 1) an MLA-based high-resolution multispectral imager and 2) the GEOSAR.

Under one proposal, the MLA will have 10 m spatial resolution, 20 nm spectral resolution, on-orbit spectral band selection (8 of 32), in-track stereo to provide two-aspect data for terrain relief information, and cross-track viewing for rapid revisitation of scenes (ref. 16). Also desirable is a wavelength range of 0.45 to 12.5 μm, 0.1 pixel band-to-band registration, and a swath width of 185 km (ref. 17). The MLA will be used for agriculture, forestry, range resources, land use and mapping, geology (rock types, soils, volcanic deposits, and landforms), water resources monitoring, and environmental monitoring (surface mining, reclamation, pollution, and natural disasters).

The GEOSAR will be the same instrument as the SEASAR, but will operate with combinations of frequencies, polarization, and incidence angles that are optimum for land remote-sensing.

The GEOSAR will complement the MLA for cartography, forest monitoring, and structural and lithologic mapping, and for studying water surfaces, soil moisture, glaciers, crops, and rangelands. Also, GEOSAR will further augment the sea ice monitoring activities of SEASAR.

I. ISSUE OF ORBITS AND NUMBER OF PLATFORMS

In the preceding discussion, there are a number of implicit and explicit assumptions made about the desirable orbits for the polar platforms. First, global synoptic coverage--whether of the atmosphere or ocean--requires frequent revisits to all points on the globe. Current practice is to have a morning and afternoon satellite. The NOAA polar-orbiting environmental satellites currently are in a typically 850 km, sun-synchronous orbit. One satellite, under plans that will be implemented later in the 1980's, will cross the Equator northbound at 1:30 p.m. The second satellite will cross the Equator southbound at 7:30 a.m. These orbits will provide the desired lighting conditions and data that are timely to the numerical weather forecasting models.

In any consideration of combining payloads, the obvious issue is the compatibility of the orbital requirements. The afternoon orbit is relatively inflexible, with respect to moving it farther away from noon. At a 1 p.m. crossing time, the orbit is well-suited to the meteorological and oceanographic missions, because both missions perform synoptic analyses; it also meets the high solar elevation angle requirement for the OCI, GOMR, and ERBE. Further, the high solar angle aids in some agricultural assessments. In the following discussion, it is assumed that the high-resolution land measurements are carried out using an early morning Equator crossing time, but this is an issue that needs to be revisited at some point. Some in the community may argue that an MLA-like instrument should be carried on both platforms.

The early morning civil meteorological and oceanographic measurements are somewhat more flexible in the choice of Equator crossing time, and the needs of the land sensors can be given greater weight. In this instance, the Landsats have successfully operated from approximately 8:30 a.m. to 9:30 a.m., while the French SPOT system is planning a 10:30 a.m. Equator crossing time. Some in the geological and mapping community prefer earlier times (ref. 18), while others in the agricultural community prefer later times. No attempt is made here to decide on a particular time; it only needs to be noted that compromises to reach a common morning time appear possible.

Reducing the number of Equator crossing times to two seems plausible. Likewise, employing sun-synchronous orbits appears

reasonable. There are measurements that can benefit from nonsun-synchronous orbits, but they do not provide convenient orbital parameters for aggregating sensors for other purposes and are likely to remain in the domain of specialized satellites and instruments. A more serious issue is that of altitude; this is addressed in subsection M from the perspective of repair and servicing.

From the perspective of the sensors, however, it seems clear that satisfactory orbits begin at 700 km and extend outward 1,000 km or somewhat beyond. Attainable instrument swath width and the need for most of the sensors to provide global repeat coverage militate toward an altitude well above some of the conceptual plans for other elements of the Space Station program. Appendix B provides a summary of past, present, and planned remote-sensing satellite orbital parameters. For purposes of the discussions in this paper, it is assumed that the required altitude is near 850 km. When these considerations are combined with those of the preceding section, the two-platform configuration described in Chapter III, Table III-1, results.

J. RELATIONSHIP TO GLOBAL HABITABILITY, IGBP, AND FUTURE LARGE-SCALE ENVIRONMENTAL PROGRAMS

A number of recent proposals have addressed the use of space systems to obtain a complete global view of the Earth and to examine the Earth from the viewpoint of a coupled, interactive system. One of these proposals is NASA's Global Habitability Program (ref. 19). A second is the International Geosphere-Biosphere Program (ref. 20). In both instances, a major multidisciplinary space-borne remote-sensing system is required. Further, a number of major environmental research studies requiring similar remote-sensing capabilities will continue to evolve, such as the World Ocean Circulation Experiment (WOCE). A recent study by the Joint Oceanographic Institutions outlines a decade-long research strategy for the period 1985-95 (ref. 21) and is certain to be followed by even more intensive research programs in the Space Station era, beyond 1995.

When the requirements of these programs are aligned with the remote-sensing capabilities of the two-platform system described in the preceding two sections (with the expectation that research payloads also could be accommodated on the platforms), essentially all the needs of these programs can be met. Indeed, in many instances an instrument will be meeting simultaneously both the needs of an operational community, e.g., the civil maritime industry, and the research community. The raw or preprocessed data needed are frequently the same; it is the subsequent processing and utilization that distinguishes the various communities of users.

K. DATA PROCESSING AND TRANSMISSION SYSTEM IMPLICATIONS

Earth observation systems have been plagued by limited approaches to data processing and distribution. These limitations have made it difficult for all remote-sensing data users, whether operational or research, to use resources effectively because of time delays, formatting, cataloging, etc.

To provide a ground data processing system for a multihundred million dollar system that is capable only of meeting the minimum research needs--and that has no redundancy or reasonable margin in throughput capacity--will negate the value of the system in numerous ways. Most of all, the U.S. value-added industry will suffer--first, from the inability routinely to provide services to customers and, second, from severely limited new markets. Likewise, educational institutions will be severely handicapped in both research and training of new talent in remote sensing and the relationship between remote sensing and traditional fields of science. Whether the system is called experimental or operational, the ground data processing system must be capable of reliably and efficiently passing the data systematically to the users. There is no advantage to be gained through backlogs of data.

In research missions, sensors age with time and require attention. Researchers, whether governmental, academic, or industrial, need to test their plans as early in a mission as possible against the often unpleasant reality of actual data. Data that accumulate--rather than being used immediately--often are never used or carry flaws that go undetected for so long that the information content of the data is not recoverable. In operational systems, where data are used to govern actions, the data must be of unquestionable quality and timely. One need only consider what a difference it would have made if a small percentage of total project cost had been invested in the original Landsat data processing system so that data were processed as they were received. It would have been possible to observe an event, analyze it, and react to it, rather than restricting all analyses to months- and years-old data. There is no doubt that the perception of Landsat data use would be quite different today had that been done.

There is another issue associated with data processing that arises in the context of the large international environmental experiments previously mentioned. These experiments will generate large and unwieldy data sets. Extracting the value from these data sets will involve the work of researchers in the academic community throughout the world. Few of those researchers will be able to support the storage and manipulation of these data. Further, the data sets resulting from

the spaceborne instrument systems will not be self-sufficient. They will require access to other large data bases of historical and correlative information. Based on these considerations, a careful systems engineering task must be carried out on the data processing, archival, archival access, and distribution systems that will support the polar orbiters. One approach to addressing some of these problems is discussed in the next section.

Related to, but somewhat distinct from, the above is the issue of direct transmission services from a polar platform. Many of the instruments previously discussed provide data that are highly perishable. These data cannot be funneled from the satellites, through a central processing facility in the United States, then distributed--over very expensive international communication links--to the numerous and varied classes of users. For this reason, a wide variety of direct downlink and recording capabilities must be provided. MRIR data in both APT and HRPT formats will be broadcast continuously. Oceanographic data also will be broadcast to ships at sea, particularly the OCI data in a format analogous to HRPT data. In addition, the present DSB transmission will continue. These functions relate to the overall data network because, in addition to providing distribution of the information to remote locations, they require onboard data processing, which will be a major issue in a polar platform system. The use of onboard processing will be aided by the use of a GPS receiver and processor on each platform.

To provide some measure of the present international reliance on these services, it is appropriate to review the number of HRPT, APT, and DSB stations in operation. Presently 85 HRPT stations exist, of which 52 are owned and operated by foreign governments. More than 900 APT stations are in over 122 countries, with most owned and operated by foreign entities. Similarly, there are seven DSB stations in five foreign countries. In all three categories, more stations are being developed in many different countries.

In addition to the direct transmission of recorded and real-time data from the sensors, it is assumed that in 1995 there will be either an operational Tracking and Data Relay Satellite System or an augmented ground tracking network to collect the global data set.

L. NATIONAL EARTH OBSERVATIONS CENTER

One of the characteristics inherent in a space platform is an aggregation of functions and sensors. A second characteristic is a high-rate flow of data through a common channel or set of channels--even after the direct transmission functions are considered. This might occur, for example, through a data

relay satellite. A third characteristic is the need to process speedily the operational data, with a frequent ground rule that all data will be processed and delivered to the users within 6 hours of acquisition. A fourth characteristic is the requirement to process, analyze, correlate, archive, and otherwise manipulate very large sets of environmental data. A final characteristic is the need to provide access to these data by a global community of operational and research users.

All these elements militate quite strongly toward the need for a very large and extraordinarily powerful central data processing facility--even when every opportunity for distributed processing by the user communities has been fully exploited. The system must be capable of rapidly processing the data from the platform, probably to the level of geophysical units or what is commonly called "level II" data. Level II processing produces geophysical data records, with the data expressed in geophysical units at the full resolution of the particular satellite sensing instrument at a specific time. Instrument transfer function and environmental effects are removed in the processing, and the data are time ordered, time tagged, and Earth located (latitude and longitude).

The facility also must produce and distribute indexes of available data sets (including some measure of the quality of the sets) and synoptic analyses that the user community can use in selecting what part of the massive quantity of data may contain the needed information. In many respects, the facility will be analogous to the National Weather Service, in that a time-critical data flow must be carefully managed, with forecast and other guidance being widely distributed and a set of synoptic charts being developed that provide first-order guidance for research or operations. The data upon which those charts are based must be available for more intensive review, or for use by those who might find it necessary to verify or challenge the synoptic analysis.

This analogy was first pointed out during the course of an Earth System Sciences Committee (one of the NASA advisory committees) meeting. The analogy, pointed out by Francis Bretherton, is particularly pertinent because it sets a different tone for the type of data system required. To meet these needs, the system must be highly reliable--with a corresponding high degree of redundancy--and sized to "pipeline" process the flow of data from the two platforms. A zero backlog rule should be imposed on the design.

In some respects, the facility will be similar to the Space Telescope Science Institute and the companion satellite control facility conceived of several years ago by NASA and its scientific advisors. In addition to being a terminus for

the flow of data from the platforms, the facility must be continuously challenged and scrutinized by the community at large. One of the most effective ways to ensure a vigorous interaction would be to surround it with facilities for scientists to visit for brief or extended periods, to carry out research projects with the data stream that is passing through the center. This would be complemented by relationships with distant academic, research, and industrial institutions, which would connect to the center via telecommunications. By the very nature of the payload outlined in the preceding sections, the facility would be multidisciplinary and would derive support from a number of agencies. In addition to the Federal operational agencies and the research community, the private sector would find it the most convenient point of access for the data they could use in the development of value-added products.

It appears entirely plausible that a joint facility (called here a National Earth Observations Center) could be created that would serve the communities that will be reliant upon a two polar platform system. NASA and the National Science Foundation (NSF) could provide the support for the center on behalf of the research community. NOAA would find this the logical home for its operational atmospheric and oceanic processing system. The U.S. Geological Survey could represent the interests of the geological community. While the facility assumably would be largely an open civilian activity, it also is in the continuing research interest of DOD to warrant support.

M. REPAIR AND SERVICING ISSUES

In discussing the previous ground data processing issues, a strong emphasis was placed on reliability, redundancy, ease of access, and throughput capacity. Similar issues apply to the polar platform itself and to servicing philosophy. The analogous considerations for the polar platform are reliability, redundancy, ease of access, cost of access, frequency of access, and flexibility. This section is devoted to those issues.

The entire environmental sciences community is exceedingly enthusiastic and optimistic about the future of all types of remote sensing from space (atmosphere, ocean, cryosphere, and land). To this community, it should be transparent whether the data stream comes from a free-flying satellite or from an astronaut-serviceable space platform. The value to the nation will pivot around the economics and ease of servicing in ensuring that the data stream is reliable, timely, and continuous. Servicing offers great potential in this process.

In the next few paragraphs, the characteristics needed in a

polar platform are reviewed and the issues associated with servicing examined. On the assumption that a polar platform is a permanent facility that must outlive many generations of instruments, the first requirement is flexibility. Either through provision of excess capacity at the outset or the use of any of a number of modular construction techniques, the platform must have the capability to change and evolve. This flexibility must be designed into the system from the very start of the program and must be carried through with great care. It is not sufficient to provide simply a large, unoccupied bus or an inflexible thermal/mechanical/data interface connection, and leave it up to the user to make do. Further, a claim of flexibility of accommodation must be supported by demonstrated reasonableness of modification costs when the inevitable changes must be made. If the platform is built in such a manner that major modifications and requalification of astronaut-rated systems are necessary, there is little possibility of cost effectiveness.

It is not evident that equipment developed for other purposes and satisfying other interface constraints is going to meld a priori into an effective polar platform. It is conceivable that flexibility and, as will be discussed next, reliability may lead to a platform configuration that is a constellation of smaller elements rather than a single large structure resembling the framework of a steel-reinforced building. If the satellite cluster approach were used, the segments would co-orbit in adequately close proximity to one another so that they would appear as a single point source to ground radio telemetry stations, and so that a single servicing mission could readily visit all segments. Interconnections among these segments could be made through microwave, optical, or cable links. These considerations must be included in NOAA's approach to coordinating its plans with the NASA plan to use elements from the inhabited station to construct the polar platform.

A second required platform characteristic is a high degree of reliability. The polar platforms and associated payloads will represent a significant portion of the civil space program activities. They are also a part that provides "payoff" rather than simply infrastructure. This large and very important investment must be protected from all plausible failures that would endanger it. Further, if the payload described in this paper were accepted, millions--even billions--of people would be relying upon the information being collected by the system. The data would be used in many life-threatening situations, so the platform cannot simply go out of service for a long period of time to await servicing. The value of the polar platforms from the NOAA perspective is the continuous data stream, not just the spare sensors.

Reliability also implies redundancy, and redundancy requirements can be related to the time between servicing missions. The time between servicing missions to a polar platform is a function of shuttle capabilities from the west coast and the cost of using those capabilities. If the servicing missions are on a basically fixed schedule--barring a major catastrophe on the platform--the instrument complement must provide reliable service over a somewhat longer period to protect service continuity. If that period is similar to or even longer than current replacement launches, the loss of a "repair on demand" or a "call-up repair/replacement" capability lessens slightly the attractiveness to all users of the polar platform data stream. If repair/replacement schedules are long and inflexible, and the cost of a servicing mission is high in comparison to the sum of the satellite replacement and launch costs, then nearly all of the attractiveness of a platform vanishes. It is the potential to make the converse of that statement true that motivates the discussion in this report.

Successful on-orbit servicing involves issues other than simply designing the equipment for convenient repair and developing astronaut techniques for carrying out the task. The first issue is whether the service person--or possibly robot--goes to the platform (at the altitude of 850 to 1,000 km) or if the platform must return to shuttle altitude for servicing. The former seems more reasonable considering the burden on the platform and the need to remove it from service during any altitude change, but it does require that either an astronaut or a robot journey 400 to 500 km above the shuttle to carry out the servicing. This is a major technical challenge, which, if accepted, would have enormous and very positive ramifications for the exploitation of space.

A large-capacity polar platform can create a phenomenal and revolutionary sensing capability, but so can large satellites. There is a legitimate rationale for servicing satellites on orbit if, and only if, the total cost of carrying out that servicing is contained within calculable bounds and is less than the cost of providing a free-flying satellite. Aggregation of functions on a large platform (whether in a monolithic or cluster configuration) would seem to contribute to the cost effectiveness of a servicing mission by allowing the sharing of costs among the instrument and platform providers. The potential for cost effectiveness and increased capabilities is intriguing enough to warrant the most serious attention.

N. OPPORTUNITIES FOR COMMERCIAL ENTITIES

Nothing in the preceding should be construed to indicate that the polar platform and its payloads are the exclusive domain of the Government. There are obviously four major roles for

the private sector, two certain and two potential:

- A certain role is that of the system developer and operator. No significant space equipment manufacturing is done within governmental facilities, and most operations control centers are run by contractors to the Government.

- A second certain role is participation as a major data user and provider of value-added services, which is largely in the private sector today and will be even more so in the 1990's.

- A potential role is that of platform provider. An aerospace company has already proposed a system that could be a predecessor to a commercial platform operation.

- Another potential role is that of a platform passenger on either a governmental or commercial platform. The economic analyses apply equally well to a governmental or a commercial user of the platform. If the polar platform is the most cost-effective way to conduct business, then private firms will prefer to pay "condominium" fees to the platform operator rather than buy their own dedicated satellites.

Thus, there is no reason to characterize the polar platform as exclusively a governmental operation. With proper consideration for the users that can be served, and a successful system development--from the perspective of user friendliness and cost effectiveness--the platform can be a major step in the utilization of space systems for all sectors of the economy, both public and private, both domestic and international. The latter is discussed in the next section.

O. OPPORTUNITIES FOR INTERNATIONAL COOPERATION

The propositions discussed in this report are ambitious. They are ambitious from the perspective of deployment of the complex sensing system, timely processing and distribution of the data that will result, and demands they place upon the Space Station program. They may be beyond the capabilities and resources of any single nation. Because the polar platforms and their payload described in this report are meant to provide a total view of the Earth's oceans, land masses, and atmosphere, international cooperation is a natural and desirable avenue for sharing benefits and costs. Precedents for joint programs exist and have been mentioned several times. The example of Advanced TIROS-N is certainly germane. A further example is the activity being initiated under the annual Economic Summit.

At the conclusion of the seventh meeting of the Economic Summit of Industrialized Nations, held in June 1982 at Versailles, the heads of state established a Working Group on Technology, Growth, and Employment. This group was formed to identify areas for further cooperation among the summit members (Canada, the Federal Republic of Germany, France, Italy, Japan, the United Kingdom, the United States, and the European Communities). Satellite remote sensing was one of the 18 topics chosen for discussion, and the United States was selected as chair, with NOAA designated to be the U.S. expert point of contact.

The objectives of this panel are to exchange information on remote-sensing programs and plans, to coordinate the programs and plans to avoid duplication of efforts, to foster compatibility of activities, to enhance the value of these programs in addressing global phenomena, and to promote more efficient uses of budget resources. All these objectives are consistent with international participation in an Earth observation system based on the polar platform.

In preparation for the 1983 and 1984 summit meetings, reports were completed for each of the 18 topics for consideration by the heads of state. Within remote sensing, participants have discussed potential collaboration in support of polar-orbiting meteorological satellites and a number of other subjects. Two working groups were formed for coordination of activities, the International Earth Observation Satellite Committee (IEOSC) and the International Polar-Orbiting Meteorological Satellite (IPOMS) group.

The Committee on Earth Observations Satellites (CEOS; previously called IEOSC) was established through the discussions of the Summit Panel of Experts on Remote Sensing from Space. In an effort to streamline coordination activities, the summit experts agreed to establish a single group to replace the former Coordination of Land Observing Satellites (CLOS), Coordination of Ocean Remote Sensing Satellites (CORSS), and the multilateral meetings on long-term planning for remote-sensing satellites. CEOS will provide a forum for the informal coordination of technical parameters of environmental, land, and ocean satellites. This broad mandate is appropriate, since many remote-sensing satellites can no longer be identified with only a single discipline. CEOS membership is open to any country or agency with an approved remote-sensing satellite program. The first meeting was held in September 1984. Participants included Canada, the European Space Agency, France, India, Japan, the United States, and Brazil. The CEOS is a forum that can be used to discuss international participation in an Earth-observing polar platform.

The 1984 summit endorsed the creation of an IPOMS group to explore mechanisms for increased international cooperation in and support for polar-orbiting meteorological satellites, and to ensure the continuity of these satellites. Therefore, IPOMS is intended to be more highly focused than CEOS. Members of the group are agencies currently contributing to or planning to contribute to the U.S. civil operational polar-orbiting meteorological satellite system. Contributions can be either direct funding or, more likely, "in-kind" support. In reviewing possibilities for increased cooperation, the new group will consider the possible use of a polar platform as a carrier for meteorological instruments. NOAA chairs this group. Canada, the Federal Republic of Germany, France, Italy, Japan, the United Kingdom, and the European Space Agency were invited to participate. Australia and Norway are considering membership. The first meeting was held in November 1984.

There is good reason for optimism in seeking international cooperation in a polar platform intended for use in Earth observations. Precedents have been established involving the contribution of hardware to operational weather satellites by a number of foreign countries. International coordinating bodies are in place that can serve as forums to advance these ideas. International specialists in remote sensing and their parent agencies are prepared to discuss these issues in depth. Most importantly, the skills and projects that will make the polar platform a next logical step in remote-sensing are in place internationally. The international community is both qualified and prepared to participate. A detailed report of international participation in environmental satellite programs is included in reference 22.

P. SUMMARY

The cumulative experience of many past, present, and future Earth observation systems that will be available by the early 1990's will make using an astronaut-tended polar platform a logical next step. If the platform proves to be an economical alternative to expendable satellites, it can serve as the carrier for a combined land, ocean, and atmospheric observation system of unparalleled capability. The need for frequently updated global synoptic models will militate toward the use of two platforms, both at an altitude of 850 to 1,000 km, one using a morning southbound and the other using an afternoon northbound Equator crossing time. The international community is prepared and can make a positive contribution to the deployment of the system; this cannot occur, however, without the vigorous support of the NASA Space Station program. NASA must accept some very hard technological challenges to make such a system feasible and be prepared to regard the needs of the remote-sensing user community and the information they

wish to gain with the same care that quite automatically must be devoted to caring for the station's inhabitants and the creation of a permanent presence in space.

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III. INTEGRATING RESEARCH AND OPERATIONAL MISSIONS

A. INTRODUCTION

Astronauts have often given up sleep to watch the panorama of the Earth passing beneath them. The fascination that people experience for the spectacular views of the Earth from space stems from their practical value, the intellectual challenges they raise, the major scientific questions they help address, and simply the great beauty associated with an unparalleled natural vista. Beauty, intellect, and human security are the wellsprings from which Earth observation derives its deserved place in the activities of nations, whether they are spacefaring or not. Mankind will continue to examine the Earth from the vantage point provided by space systems, using both human and robot eyes, and the NASA Space Station program will create some of the most important opportunities to gain the clearest and most comprehensive views.

In the beginning, middle, and end of every space applications program lies an interwoven science program. Space applications programs in Earth observations are built upon the scientific results obtained in research missions. Data produced by applications or operational missions also are essential to numerous scientific investigations--some directed at understanding measurements that have already been declared "operational." At the end of one instrument generation in an Earth observation program comes the scientific questions regarding what the next generation of instruments and measurements should be, to say nothing of the continuing retrospective use of data gathered by instruments long since superseded by more advanced models. Thus, science activities--and not simply scientific foundations--are woven into every aspect of an Earth observation program, from the earliest conceptualization phase to the last use of data drawn from an archive years after the mission has been completed.

For these reasons, when a given discipline area is discussed in the following paragraphs, research and operational needs are not rigidly separated, but are examined jointly. No operational program can remain effective without a vigorous accompanying research program. Similarly, no research program in Earth observation should be conducted without an awareness of operational programs, their objectives, and the data they produce. These two aspects of Earth observations, research and applications, or operations are mutually supportive and synergistic; therefore, the polar platform will be an integrated research and applications Earth observation system.

In recent years, much attention has been paid to studying the

Earth as a total coupled, interacting system. NASA's Global Habitability program (ref.1), the International Geosphere-Biosphere program [renamed Global Change (ref. 2)], and other efforts are aimed at complementing the traditional studies of the Earth (e.g., biology, geology, meteorology, and oceanology) with an examination of the interactions among these specialized areas. For example, oceanography and meteorology are disciplines with long and distinguished histories, but it is well recognized that they are not mutually exclusive, independent fields of study. Rather, they are connected and have many strong interactions that cannot be ignored. The view from space is ideal to provide the global synoptic analysis of the coupled machine that makes up the Earth. Measurements from space are vital, and the polar platform is the ideal carrier for an integrated instrument suite that permits simultaneous, multidisciplinary observations.

In the succeeding sections, the required observations will be characterized for each of the major scientific disciplines supported by Earth observations. The review of observations will begin with the solar-terrestrial environment surrounding the Earth and will move downward through the atmosphere to the hydrosphere, land, and biosphere. These discussions are not intended to serve as a summary of what is known or has been accomplished in each discipline using Earth observational techniques. They are only intended to state some of the principal views that will guide the selection of payloads for the polar platform. Further details about past and present measurements are given in a review paper prepared by one of the authors that will be published in 1985 (ref. 3). Note also will be made in each section of the synergism that measurements in one category have with those of other disciplines. These sections are followed by an examination of the necessary attributes of an Earth observation polar platform that combines research and operational functions. Much of this material relies on two documents, references 4 and 5.

B. SOLAR-TERRESTRIAL INTERACTIONS

The sun-Earth system is highly dynamic, with a varying solar flux of fields and particles that exerts many different influences on the terrestrial environment (ref. 6). The solar flux passes through the exosphere, past the thermopause, and into the thermosphere (between 90 and 500 km in altitude). In this region lies the ionosphere, driven by the diurnal cycle of the solar flux. Below the thermosphere lies the middle atmosphere, bounded by the mesopause and tropopause and including the mesosphere and stratosphere. This section deals mainly with the exosphere, thermosphere, and upper sections of the mesosphere. The next section will discuss the stratosphere and the troposphere (the region below 10 km where weather is produced).

The investigations of the space physics of the solar system have been among the most exciting intellectually of any of the space program. Yet, it would be incorrect to regard this field as one of pure research. Solar activity can have an adverse impact on long-distance and high-latitude radio communications, satellite operations, oil pipeline operations, electric power transmission systems, high-altitude aircraft flight, and human spaceflight. These effects have led to a program of solar event alerts, warnings, and forecasts that has been in existence for many years (ref. 7).

The previously referenced program has in turn led to the requirement to fly space environment sensing systems on the civil environmental satellites [recently the TIROS-N and Advanced TIROS-N (ATN) series] and the weather satellites flown under the DMSP. The current ATN carries a Space Environment Monitor (SEM) consisting of two instruments, a total energy detector (TED), and a medium energy proton and electron detector (MEPED). The TED measures the total energy deposited by precipitating magnetospheric electrons and protons over a range from 0.3 to 20 keV. The MEPED uses four directional sensors and one omnidirectional sensor to measure protons, electrons, and ions having energies in the range from 30 to greater than 60 keV (refs. 8 and 9).

The Block 5D-2 version of the DMSP carries five sensors in its space environment monitoring subsystem. They include a precipitating proton-electron cumulative-dose spectrometer called SSJ/4, a topside ionospheric plasma monitor called SSIE, a scanning gamma and X-ray sensor called SSB/A, an X-ray intensity detector called SSB/S, and a high-frequency receiver to monitor ionospheric phenomena called SSIP (ref. 10).

The SSJ/4 measures the accumulated electron dose over a range of 1 to 10 MeV and protons for the range greater than 20 MeV. The SSIE has an electron sensor to measure ambient electron density and temperature, as well as the electrostatic potential of the vehicle. It has an ion sensor that makes the same measurements for the ion species as the electron sensor, but also measures the average ion mass.

The SSB/A measures X-ray intensity as a function of energy from nominally 2 keV to more than 100 keV. The SSB/S is a companion X-ray intensity detector measuring energies in levels of 25, 45, 75, and 115 keV. The SSIP monitors the ionospheric noise breakthrough frequency, a parameter used in ionospheric forecasting.

In addition to the sensors mentioned, it is expected that the solar-terrestrial community will require new research and new operational sensors. An excellent illustration of the latter is the solar soft X-ray imaging sensor that is proposed for

flight on either a civil or defense satellite (ref. 11). This sensor would provide a greatly improved forecast capability, because it would provide a spatial characterization of the "source function" for insertion into the propagation models of the NOAA Space Environment Laboratory.

For the reasons given, it is assumed that a polar platform will carry an advanced SEM, which will include at a minimum the sensors currently carried by the ATN and DMSP, and probably an X-ray imager. This operational set will be complemented by research instruments derived from the Dynamics Explorer (DE) (refs. 12 and 13), Solar Maximum Mission (SMM) (ref. 14), and other research programs.

In addition to these instruments, there is the need to measure the total radiation budget of the Earth. The Earth Radiation Budget Satellite (ERBS) and the companion Earth Radiation Budget Experiment (ERBE) instruments that will be carried on a number of the ATN series are but the first step in this process. This device, or set of instruments, is referred to as the Earth Radiation Budget Instrument (ERBI). The objective of these measurements is to determine the monthly average radiation energy budget of the Earth on regional, zonal, and global scales. It is inevitable that it will be necessary to continue these measurements on the polar platform.

To provide a timely, global view of the solar-terrestrial environment of the Earth, and to provide continuous observation of the sun at X-ray wavelengths, it would be desirable to have two advanced SEM in orbit at once. The needs of the research instruments would be addressed case by case. The ERBI requires a high solar angle and therefore, would, only be carried on a polar platform that crosses the Equator near noon.

C. EARTH'S ATMOSPHERE AND METEOROLOGY

Space provides the best viewpoint from which to observe the atmosphere and its varying parameters. These variations involve changes in the constituents of the atmosphere over seasonal or longer time spans, and the rapid changes associated with the weather. The preceding section described the measurements that aid in understanding the flow of solar energy in all its forms into the atmosphere. The next step is to examine the effect of that energy flux.

The thermosphere was the principal subject of the preceding section, but the lower thermosphere and middle atmosphere are also the targets of the NASA Upper Atmosphere Research Satellite (UARS). The satellite will carry 11 instruments to measure, on an integrated, global scale, the concentration of ozone. UARS also will measure the energy balance and dynamics

of the middle atmosphere. Thus, energy inputs, temperatures, and stratospheric and mesospheric winds will be examined.

The UARS measurements will be complemented by the continuing measurements carried out on the operational polar-orbiting environmental satellites, using the Solar Backscatter Ultraviolet Spectral Radiometer, model 2 (SBUV/2). The device, flown for the first time on NOAA 9 in December 1984, is a spectrally scanning ultraviolet radiometer that operates over the range from 160 to 400 nm. It measures the solar spectral irradiance over that range, and the total ozone concentration in the atmosphere with an accuracy of 1 percent, and it provides data from which the vertical distribution of ozone in the atmosphere can be determined to an accuracy of 5 percent. A later generation of this instrument, termed the Global Ozone Monitoring Radiometer (GOMR) (ref. 4), is an excellent candidate for international cooperation; more will be said of this later.

These instruments will give rise to a series of research devices that will study the seasonal, annual, and multiyear variability of the constituents of the atmosphere. One of the questions that will be addressed is the relationship between man's activities and the ozone layer. NASA has outlined a proposed research instrument complement for the polar platform, called the Atmospheric Physical and Chemical Monitor (APACM), to address these issues (ref. 5). Neglecting a Doppler lidar that will be discussed later in this section, the APACM includes an upper atmosphere wind interferometer, tropospheric and upper atmospheric composition monitors, and energy and particle monitors.

The upper atmosphere wind interferometer uses a high-resolution, multiple-etalon Fabry-Perot interferometer to measure the Doppler shift of molecular and atomic absorption and emission lines in the atmosphere. The device provides a vector wind field from the tropopause to the stratopause with an accuracy of a few meters per second.

Tropospheric composition monitors will employ passive interferometers and spectrometers tuned to appropriate wavelengths, and other total column abundance measurements such as those carried out by the Measurement of Air Pollution from Satellites (MAPS) experiment carried by OSTA-1 on STS-2 in November 1981. Vertical profiles will be measured using lidar techniques. A Laser Atmospheric Sounder and Altimeter (LASA) has been proposed by NASA (ref. 5).

Upper atmosphere composition monitors will employ a variety of ultraviolet, visible, infrared, and submillimeter spectrometers and radiometers. They will be complemented by a microwave limb sounder.

The energy and particle monitors considered for inclusion with the APACM properly would be a part of the SEM package and the ERBI discussed in the preceding section. The reduced APACM (listed in Table III-1) has the Doppler lidar and energy/particle monitors removed.

In addition to the above measurements of the constituents of the atmosphere and their variations, it also is necessary to continue to monitor the dynamic patterns that are associated with the weather. The current ATN satellite carries an AVHRR that provides radiometrically accurate measurements in five visible and infrared spectral bands. A later version will add a time-shared sixth channel (ref. 15). The AVHRR is used to forecast local weather in some countries and to measure snow cover, ocean and lake ice, and sea surface temperature. When prepared as a mosaic image, the data also are used to replace partially geostationary satellite imagery when those satellites fail unexpectedly. It has a current spatial resolution of 1 km (refs. 8 and 9), but user demand in meteorology and other disciplines is likely to lead to a 500 m resolution in the future.

Similarly, it is likely that the same demand will lead to a requirement for a 10-channel instrument rather than the 6-channel instrument that will meet the needs of the next series of ATN satellites (ref. 4). Thus, the operational requirement will be a relatively straightforward derivative of current technology. This sensor will be called the Medium-Resolution Imaging Radiometer (MRIR). The MRIR would have superior radiometric and spectral qualities--and comparable spatial resolution--to the Operational Linescan System (OLS), which is the primary imaging device on the DMSP (ref. 10).

NASA has proposed a similar but more advanced instrument for the polar platform. It is called the Moderate-Resolution Imaging Spectrometer (MODIS) (ref. 5). It includes the capabilities of the Ocean Color Imager (OCI), an instrument that will be discussed in the next section. The MODIS is to provide visible and infrared radiometric imaging at a nominally 1 km resolution over land and 4 km resolution over the open ocean in, perhaps, 100 spectral bands. It would encompass the full capability of the MRIR and OCI instruments and additional spectral channels. As a research instrument, it would provide direction for future improvements in the medium-resolution sensors. It is tempting to think of a merger of the MODIS, MRIR, and OCI functions, but it may be most cost effective to initiate operations with the MRIR and OCI, add the MODIS when ready for a period of parallel operations, then phase operations over to a MODIS-derivative at an appropriate future date. Because of the ocean color bands, the MODIS would be placed only on the afternoon platform.

Table III-1
Payload for a Two-Polar Platform Observing System
Combining Research and Operational Missions

Category/Instrument	Platform Alpha	Platform Beta
Solar-terrestrial		
1. Advanced SEM [a,c]	X	X
2. ERBI [a,c]	X	
Atmosphere/meteorology		
3. MRIR [a,c]	X	X
4. MODIS [b]	X	
ATOVS [a,c]		
5. HIRS [a,c]	X	X
6. AMSU-A [a,c]	X	X
7. AMSU-B [a,c,d]	X	X
8. GOMR [a,c,d]	X	
9. APACM [b] (reduced, see text)	X	
10. LASA [b]	X	
11. Windsat [b]		X
Ocean/coasts		
12. SEASAR [a,c,d]	X	
13. NSCATT [a,c,d]	X	X
14. Altimeter [a,c,d]	X	X
15. AMR/HMMR [a,c,d]	X	X
16. SSM/I [a,c]	X	X
17. ATSR [a,c,d]	X	X
18. OCI [a,c]	X	
Solid Earth/vegetation		
19. MLA [a]		X
20. HIRIS [b]	X	
21. GEOSAR [a,c,d]		X
Data services		
22. Data collection and platform location [a,c,d]	X	X
23. Search and rescue [a,c,d]	X	X

a. Principally operational instrument
b. Principally research or developmental instrument
c. Currently flying or scheduled to fly before the Space Station
d. Potential internationally provided instrument

Satellite laser systems have been proposed as tools for obtaining tropospheric wind measurements directly. The technology required by such systems appears to be almost at hand, but there remain questions about the adequacy of the global destruction of tropospheric aerosol target particles, spacecraft power and communications reserves, and data handling capabilities (refs. 16 and 17).

D. OCEANS AND COASTS

When a map showing the measurement of surface and upper air weather conditions is examined, the most obvious characteristic is the sparsity of data over the oceans. One of the most fundamental contributions that satellites have made to global weather forecasting is their provision of data from regions where data previously were unavailable. This contribution was most evident in the Southern Hemisphere, where the ocean area dominates that of the land. As weather forecasts extend farther into the future, detailed information about atmospheric conditions over the oceans becomes more important. Likewise, as modeling becomes increasingly sophisticated, attention must be given to effects that were negligible in less detailed analyses. Atmosphere-ocean coupling is one such effect and has important implications in both near-term and climate-scale forecasting.

The importance of understanding the dynamics of the ocean is evident, whether the objective of the understanding is to advance knowledge or to support maritime operations. Further, the technical means are at hand to carry out detailed observations that serve both objectives.

A number of instruments have been tested in space and found to be highly successful; they will find a permanent operational home in the space applications programs of the United States and other nations. They include synthetic aperture radars, radar scatterometers, radar altimeters, microwave radiometers, and ocean color imagers. When combined with the MRIR and a microwave imaging device called the SSM/I, carried on the DMSP satellites, a powerful collection of ocean instruments emerges. The role they can play will be discussed later.

It is useful to consider what information is desired by the maritime community as represented--perhaps by the captain of a shipping vessel, a fisherman, or an oil well drilling platform operator. It is obvious that the location of sea ice, ocean currents, regions of high biological productivity, cold upwellings, ocean temperature boundaries or fronts, the range of wave heights, and surface wind and wave directions and magnitude are some of the more elementary parameters that a maritime operator wants to know (ref. 18). Because these are varying quantities, the sampling frequency must be commen-

surate with the significant period of variation. The instruments that will be reviewed are aimed specifically at these data. In addition to their immediate importance to the person at sea, they also contribute to the improvement in weather forecasting.

Two satellites, Seasat and Nimbus-7, paved the way in ocean observations. From these early experiments have come the plans for a series of United States and foreign satellites that include Geosat, N-ROSS, TOPEX/Poseidon, ERS-1, MOS-1, JERS-1, Radarsat, and others (ref. 3). Among the most important sensors was the SAR carried by Seasat and planned for Europe's ERS-1, Japan's JERS-1, and Canada's Radarsat. Generally in ocean areas and particularly in high-latitude regions, cloud cover is prevalent and negates the effective use of visible and infrared wavelength sensing systems. The SAR, by operating at microwave wavelengths, penetrates cloud cover and provides high-resolution imagery of the oceans, coasts and, notably, sea ice (ref. 19). Further discussions about the characteristics and applications of space-borne radar systems are given in references 20, 21, and 22.

Thus, while operational instruments such as the MRIR and research instruments such as the ATSR will continue to be flown, the user community desires all-weather capability. Current operational users must wait for days or even weeks to obtain data in some areas of the world (ref. 23). This impetus has led to the plans for precision microwave radiometers that will be flown on the N-ROSS and ERS-1 satellites. The N-ROSS radiometer is called the Low-Frequency Microwave Radiometer (LFMR) (ref. 24). The device will have a temperature accuracy of nominally 1° K, and a spatial resolution between 10 and 25 km. A continuing need for such data can be expected, and an outgrowth of the LFMR will be flown on the polar platform. It has been termed an Advanced Microwave Radiometer (AMR) (ref. 4). NASA has proposed a research instrument called the High-Resolution Multifrequency Microwave Radiometer (HMMR) (ref. 5). It seems likely that a single instrument can meet the needs of both the operational and research communities.

Both Seasat and Nimbus-7 carried an experimental sensor called the Scanning Multichannel Microwave Radiometer (SMMR). The SMMR demonstrated the ability of a microwave instrument to measure sea ice (extent and age), sea surface temperature, precipitable water vapor, wind speed, and other atmospheric and oceanographic parameters. It has been followed by a microwave imaging device, the SSM/I, that will be carried on the future DMSP and N-ROSS satellites (ref. 10). The SSM/I will continue and extend the SMMR measurements operationally. Because the data products can be transmitted at a relatively low data rate, and because they are of value to many in the

maritime community, it is expected that this sensor will be employed well into the 1990's. It is important to note that the instrument provides wind speed, a scalar quantity, rather than the vector quantity of wind velocity. One of the data processing challenges will be the imposition of globally incomplete vector scatterometer wind fields on a much denser, and essentially complete, grid of wind speeds derived from multiple SSM/I and the subsequent determination of unique solutions for the total global wind field. SSM/I would be flown on both polar platforms to provide a sufficient sampling rate.

Nimbus-7 carried a Coastal Zone Color Scanner (CZCS) that has proven to be a great success in detecting near-surface phytoplankton biomass in the open ocean, and in tracking the changes in mesoscale ocean features (ref. 25). This experimental sensor, now long past its expected lifetime, is being used on a quasioperational basis. Both research and operational user community demand will lead to a continuation of these measurements. NASA has proposed that the ocean color spectral bands be a part of the MODIS. Because there is some technological uncertainty about the appropriateness or feasibility of incorporating such diverse requirements in a single instrument, it is suggested here that an OCI derived from the CZCS be flown as an operational instrument until such time as the development and demonstration of the MODIS instrument is complete. The OCI requires a high solar angle, so it would be placed only on the afternoon platform.

The next section addresses the subject of remote sensing of the solid Earth and vegetation. Just as an overlap was observed between the sensors used for meteorology and oceanography, a similar overlap will be seen between those two areas and the land-related sensors.

E. SOLID EARTH AND VEGETATION

One of the more surprising results of the meteorological satellite program has been the utility of the AVHRR in land remote sensing (ref. 26). In spite of its coarse spatial resolution, the high spectral and temporal resolution have made the AVHRR a very useful adjunct to higher spatial resolution sensors. Notably in agricultural applications, the AVHRR is an excellent low-cost device for change detection (ref. 27). Particularly favorable results have been obtained in monitoring African vegetation (ref. 28). Thus, the MRIR and MODIS sensors discussed previously with respect to their meteorological and oceanographic applications are also of value in the land sciences.

The Multispectral Scanner (MSS) and Thematic Mapper (TM) of the Landsat series have paved the way for precision multi-

spectral analysis of surface features at spatial resolutions of 80 m and 30 m, respectively (ref. 3). The French SPOT system will follow later in 1985. Multilinear Array (MLA) detector technology is advancing rapidly. Even though currently it is found principally in the visible and near-infrared bands, it is expected to advance to new spectral regions before the deployment of the polar platform. At least one commercial proposal has been advanced that would provide 10 m spatial resolution, 20 nm spectral resolution, on-orbit spectral band selection (8 of 32), and along-track stereo and cross-track revisit pointing capability (ref. 29). While the likelihood of this particular design being carried forward to operations is uncertain, it does give some measure of what industry feels confident in building.

NASA has proposed a high-resolution device to complement the MODIS. The High-Resolution Imaging Spectrometer (HIRIS) is an even more advanced concept than the MLA. It allows highly detailed spectroscopic analyses to be made of relatively localized areas (i.e., it is a directed sensor that is targeted on a particular area rather than a sensor that is used for global "mapping" functions).*

The HIRIS is derived from the proposed Shuttle Imaging Spectrometer Experiment (SISEX) (ref. 30). The SISEX provides 128 spectral bands over the range 0.4 to 2.5 m, with a 10- to 20-nm spectral resolution. As with the *MRIR and MODIS*, it seems likely that the MLA would be the near-term operational sensor until development of the HIRIS is completed and well-understood results are produced. The MLA sensor would be placed on a morning platform to retain continuity of scene lighting conditions with the existing and future archive of Landsat and SPOT data. The HIRIS could be placed on the same platform or, as proposed by NASA, on the afternoon platform. This would permit correlative research to be carried out between the HIRIS and the MODIS. For research and midlatitude measurements, the HIRIS could be carried on the inhabited module or co-orbiting platform.

Just as ocean and meteorological observations benefit from sensors having all-weather capability, land sensing experiences the same difficulties in many areas of the world. Sensors having the capability to penetrate vegetation or dry sand cover provide valuable insights into regional geology. This is particularly true of tropical rain forest and desert regions. Although Seasat was directed at ocean applications, many of its scenes were of land. Those scenes were found to

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*The MSS, the TM, and the sensors of a more cartographic character fall into this category.

have great value. More recently, successors to the Seasat SAR have flown on the space shuttle under the name SIR.

By providing variable incidence angles, polarizations, and frequencies, optimum sensor parameters are being developed for a number of applications. As of this writing, the optimum combinations of parameters are not yet clear. The best design for ocean applications may or may not be optimum for land applications, as noted in the section on oceanographic measurements. A SAR aimed at land applications is referred to as a GEOSAR to allow for the possibility of two different designs. A single instrument would serve both research and operational users, as in the case of oceanography. The GEOSAR would occupy the same position on the morning platform that the SEASAR would occupy on the afternoon platform.

This discussion completes the review of the high-priority research and operational instruments for the polar platform. The next step is to discuss the arrangement of the instruments on the afternoon and morning platforms, and to discuss some of the general issues surrounding the polar platform.

F. POLAR PLATFORM AS A VANTAGE POINT

The instruments described in the last several sections of this chapter represent the most powerful tools ever conceived for the study of the Earth and its environment. A manifold, multidimensional view of the Earth and its radiation environment, atmosphere, ocean, land, and biota is attainable. This complex, yet objective, view can only be obtained by means of a system such as the polar platform.

The observing system is too complex to ensure reliable operation in the absence of servicing and the capacity to carry ample redundancy. The system is too costly an investment to be treated as an expendable commodity--its cost must be prorated over many years to reach cost effectiveness (ref. 4).

A high-capacity, astronaut-serviced system is essential to the realization of the Earth observation capabilities described in this chapter. It can be stated without equivocation that the polar platform of the NASA Space Station program is mandatory for the full realization of the potential of Earth observation systems.

The reader who is not intimately acquainted with all the observing systems may find the numerous acronyms, and the sensors they represent, more than just a little confusing. Table III-1 summarizes the discussion to this point and assigns each of the candidate passengers for the two polar platforms to its position. Table III-2 provides a reiteration of the acronyms used with the instruments.

Table III-2
Acronyms Used With the Instruments

Instrument	Acronym	Definition
1	SEM	Space Environment Monitor
2	ERBI	Earth Radiation Budget Instrument
3	MRIR	Medium Resolution Imaging Radiometer
4	MODIS	Moderate Resolution Imaging Spectrometer
-	ATOVS	Advanced TIROS Operational Vertical Sounder
5	HIRS	High-Resolution Infrared Radiation Sounder
6,7	AMSU	Advanced Microwave Sounding Unit
8	GOMR	Global Ozone Monitoring Radiometer
9	APACM	Atmospheric Physical and Chemical Monitor
10	LASA	Lidar Atmospheric Sounder and Altimeter
11	WINDSAT	Doppler Lidar Wind Sensor
12	SEASAR	Sea-related Synthetic Aperture Radar
13	NSCAT	N-ROSS Scatterometer
14	-	
15	AMR/HMMR	Advanced Microwave Radiometer/High-Resolution Multifrequency Microwave Radiometer
16	SSM/I	Special Sensor Microwave Imager
17	ATSR	Along-Track Scanning Radiometer
18	OCI	Ocean Color Imager
19	MLA	Multilinear Array
20	HIRIS	High-Resolution Imaging Spectrometer
21	GEOSAR	Land-related Synthetic Aperture Radar
22	-	
23	-	

The assumption has been made that the platforms will be placed in orbits commensurate with the current or planned polar-orbiting environmental satellites or future land remote-sensing missions. This leads to sun-synchronous, near-polar orbits at an altitude between 800 and 900 km, and with Equator-crossing times of 8 to 10 a.m. southbound and nominally 1 p.m. northbound.

From these vantage points, a comprehensive view of the Earth can be obtained with sufficient frequency to meet all meteorological and oceanographic forecasting requirements. Further, the sensor suites allow the correlative measurements that will be necessary to discover the subtle connecting mechanisms that tie the various spheres together.

G. COMMUNICATIONS AND A SYSTEM OF GLOBAL SERVICES

The objective of the payload defined in Table III-1 is to obtain a comprehensive view of the world and to revise that view on a frequent time scale to meet human needs. This objective requires that considerable attention be paid to data processing and distribution. The incorporation of operational meteorological and oceanographic sensors on the polar platforms places important boundary conditions on the data processing and communications subsystems.

Some processing must be done on board, e.g., the generation of lower resolution imagery or other products for direct broadcast. Several direct links to and from the platforms will be necessary. These links would include automatic picture transmission, high-resolution picture transmission, and direct sounder broadcasts for the international meteorological community (more than 1,000 receiving stations worldwide). Similar downlinks for the oceanographic community and transmissions to foreign ground stations of data from the land-related sensors also would be included. The platforms would employ the TDRSS for global data collection to support U.S. activities.

The principal focus of the previous discussion has been on Earth observations, but there are two other important sensor systems that will be carried on the platforms. They have already been included in the last category in Table III-1. They are the data collection and platform location system and the search and rescue system.

The current polar-orbiting environmental satellites carry a data collection and platform location system called the Argos system, provided by France (ref. 31). A receiver on the ATN satellites detects the signals from small transmitters that may be located on the land or sea, or in balloons. Land transmitters typically broadcast meteorological data, but also

have been used in volcanology and seismology. Snow data and hydrological measurements for river basin management are other frequent uses for land transmitters. Sea transmitters are used for both oceanographic and meteorological applications and measure atmospheric pressure and temperature, ocean winds and waves, and marine pollution, salinity, and biological parameters. An upgraded Argos system is a very likely payload for the polar platforms. NASA has proposed a similar system called the Automated Data Collection and Location System (ADCLS), but only one of the two would be necessary.

The second system is the international search and rescue system. The ATN satellites carry equipment provided by Canada and France that detects the faint emergency signals from crashed aircraft or ships in distress. Complementary equipment is carried on two Soviet satellites, in a splendid example of international cooperation that has saved more than 300 lives in a little more than 2 years. Such equipment should be placed on any available civil satellite, including the polar platforms. The waiting time for a victim in an emergency situation is related directly to the frequency with which an area of the Earth is observed, which is in turn related directly to the number of search and rescue-equipped satellites in orbit.

For all these reasons, the polar platforms will be the hub of an international set of important services. It is essential that the importance of those services be understood and considered in the establishment of the capabilities and design constraints of the polar platform.

H. PLATFORM SERVICING

It is evident that the central capabilities that make the polar platform of value to the Earth observations community are the large and flexible capacity that is expected and the ability to do on-orbit servicing. Capacity controls the amount of redundancy that can be employed, and the servicing approach and schedule dictate the required design lifetime needed by a sensor and its various subsystems. These parameters will determine the economics of future Earth observations (refs. 4 and 32).

The bounds within which favorable servicing costs must lie are well established, because the annual investment in operational environmental satellites and research missions is well known.

If servicing can be shown to reduce those costs dramatically, or to allow greater capability within those costs, an astronaut-serviced polar platform will have the strongest justification possible. A demonstration of this justification is within grasp of the space program.

I. INTERNATIONAL PARTICIPATION

Earth observation is a global science--a science in which international cooperation and participation is not simply desirable, but is mandatory. The services resulting from this science are equally global in character. The relevant model for international participation in the polar platforms has been well established through the activities surrounding the current ATN satellites. The satellites already have a strong international element, and efforts are underway to increase it even further.

The current satellites carry two instruments from France, one from Canada, and one from the United Kingdom. Discussions are underway among the United States and a number of other countries, using a forum that developed under the Economic Summit process, to expand participation (ref. 32). It is fully expected that substantial new projects will be proposed; the level of contribution would be as high as the provision by the international community of a polar platform. Even if this were not achieved, very large contributions of major science and applications sensors are inevitable. The listing of instruments in Table III-1 has been annotated to indicate which instruments already are being provided or could be provided by the international community as an outgrowth of current programs. Even some of those that are not annotated could be provided, but the more restrictive assumption was used to show the wide range of substantive possibilities.

J. SUMMARY

The polar platform of NASA's Space Station program can make possible the most sweeping examination of the Earth imaginable. Composite suites of sensors will allow correlative measurements to be made of the Earth's radiation environment, atmosphere, weather, ocean, land, and biosphere. The complex observation system described can be created in no other way. A conventional, expendable satellite that does not employ servicing would be too costly and unreliable. Only an astronaut-serviced polar platform has the potential to bring this capability to reality--both technically and economically.

There is no doubt that the creation of the capability described in this report is a major technical challenge. The difficult servicing and data management advances that it requires will not be easy. Yet, if this challenge is accepted, the entire world will benefit from improved understanding and vital services. That is an excellent objective for the NASA Space Station program.

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IV. COST RATIONALE: SPACE STATION POLAR PLATFORM VERSUS CONTINUANCE OF POLAR METSAT PROGRAM

The costs and complexity of satellites are increasing rapidly. Weather satellites have grown in cost from $25 million per satellite (excluding launch costs) to several times that cost in the 1990's. In most cases, the cost of sensors from one generation of polar satellites to the next has at least doubled. Further, launch costs are escalating rapidly. For the same satellites mentioned, launch costs have climbed from $7 million per satellite to $30 million for the last of the Atlas series that will be used late in this decade. Costs for dedicated polar launches in the 1990's are indeterminably higher than $30 million, but the most optimistic observers expect a large increase of at least 100 percent. Pessimists deal in numbers more suited to astronomical dimensions than support costs for operational Earth observation systems. Obviously, these numbers dramatically affect the economic analyses alluded to.

While the geostationary satellite users have obtained some benefit from the past decade's development activities in launch vehicles and upper stages, the users of polar-orbiting satellites have seen little other than reductions in capabilities, uncertainties about future launch vehicle availability, scant information about the ability to schedule launches when they are needed, and unpredictable--but rapidly escalating--costs. The predicted improvements that were much heralded in the early 1970's are notably absent in the middle 1980's. The remote-sensing user community, therefore, will be looking for rigorous analyses of platform benefits, and will have some understandable skepticism about the underlying assumptions and the sensitivity of the analyses to changes in those assumptions. The uncertainties that users presently face in planning for the deployment of systems in polar orbit obviously also relate directly to the cost and schedule for servicing a polar platform. The search for new approaches to polar orbit operations is the subject of the following discussion.

Because of the increasing costs of space systems, it seems less and less reasonable to discard adequately functioning subsystems and instruments just because other subsystems or instruments have failed, which is exactly what is currently done when an Earth observation satellite is replaced. The current practice is to replace a satellite when some of its instruments or some of its subsystems are no longer capable of satisfying the highest ranking observational needs; replacement occurs in spite of the capabilities that remain available. These remaining capabilities may be quite extensive, given the highly variable and differing lifetimes of the

numerous instruments and subsystems that make up an Earth observation satellite. Some 70 percent of the systems on polar-orbiting weather satellites are still serviceable when the satellites are decommissioned. The current expected life of a polar-orbiting meteorological satellite is only 2 to 3 years.

Table IV-1 gives the projected cost breakdown for maintaining the current two-polar metsat system through the year 2000. The assumptions used in deriving these figures were as follows:

- A NOAA spacecraft will be launched every 12 months to maintain the two-polar fleet
- The lifetime of each NOAA spacecraft will be 24 months
- Inflation will remain at 7.5 percent per annum

As can be seen, the cost of maintaining the two-polar spacecraft system through the year 2000 is almost $3 billion. Of this total, the cost of the spacecraft themselves accounts for over 57 percent of the total, or $1.7 billion.

By planning the NOAA operational payloads on the NASA-provided Space Station polar platforms, this spacecraft cost is entirely eliminated. However, there could be a significant initial increase in the cost of NOAA instruments because of their integration into the platform. It also is anticipated that launch costs to NOAA would remain about the same after conversion to polar platforms, because the funds that would have been used to launch expendable NOAA spacecraft would be used instead to share in the cost of servicing missions for the polar platform (anticipated to take place yearly). Even so, the total savings to NOAA by converting from expendable spacecraft to the Space Station platforms still could be very large. These savings could reduce the added funding burden that will result from the transition of research instruments to an operational status.

Table IV-1
NOAA Costs for Maintaining a Two-Polar
Metsat System FY1985-2000

	Cost (K)	Percent
Spacecraft	1,714,821	57.7
Instruments	606,560	20.4
Launching	659,299	22.1
Total	2,980,680 K	100 %

APPENDIX A

LISTING OF SENSORS

Table A-1
Listing of Sensors

Satellite	Launch Date	Vis/IR Radiometer	Passive Microwave Radiometer	Atmospheric Sounder	Radar Scatterometer	Radar Altimeter	Synthetic Aperture Radar	Ocean Color Radiometer
ITOS	1972	VHRR, SR	0	VTPR	0	0	0	0
ERTS-A	1972	MSS, RBV	0	0	0	0	0	0
DMSP	1973	SAP	0	SEE	0	0	0	0
GEOS-3	1975	0	0	0	0	RAS	0	0
Nimbus-6	1975	0	ESMR	HIRS, THIR, SCAMS	0	0	0	0
HCCM	1978	SR	0	0	0	0	0	0
Nimbus-7	1978	0	SMMR	THIR, SAMS	0	0	0	CZCS
Seasat	1978	VIRR	SMMR	0	SASS	ALT	SAR	0
TIROS-N	1979	AVHRR	MSU	TOVS (HIRS/2, MSU, SSU)	0	0	0	0
Landsat-5	1984	MSS, TM	0	0	0	0	0	0
Geosat	1985	0	0	0	0	RA	0	0
SPOT	1985	HRV	0	0	0	0	0	0
IRS-1	1985	LISS	0	0	0	0	0	0
DMSP/ATN	1985	OLS	SSM/I	SSM/T	0	0	0	0
MOS-1	1986	MESSR, VTIR	MSR	0	0	0	0	0
ERS-1	1988	ATSR-M	ATSR-M	ATSR-M	AMI	E-Alt	AMI	0
N-ROSS	1989	0	SSM/I, LFMR	0	SCATT	RA	0	0
TOPEX	1989	0	0	0	0	T-Alt	0	0
NOAA-Next	1989	AVHRR	AMSU-B	AMSU-A, B/HIRS-2	0	0	0	0
Radarsat	1990	TBD*	0	0	TBD*	TBD*	SAR	0

* To be determined

APPENDIX B

SUMMARY OF SATELLITE ORBITAL CHARACTERISTICS

Table B-1
Satellite Orbits

Satellite	Launch Date	Altitude (km)	Inclination (degrees)	Type	Nodal Period (minutes)	Equator Crossing Time
ITOS	1972	1451	101.7	Polar/Sun-synchronous	114.9	0900 LST
ERTS-A	1972	907	99.9	Polar/Sun-synchronous	103.1	0850
DMSP	1973	837	98.8	Polar/Sun-synchronous	101.6	0600 and 1200
GEOS-3	1975	843	115.0	General	101.8	NA
Nimbus-6	1975	1097	100.0	Polar/Sun-synchronous	107.3	1200
HCMM	1978	620	97.8	Polar/Sun-synchronous	96.8	1400
Nimbus-7	1978	946	99.3	Polar/Sun-synchronous	104.0	1200
Seasat	1978	784	108.0	General	100.7	NA
TIROS-N	1979	854	98.8	Polar/Sun-synchronous	102.0	0730 and 1400
Landsat-5	1984	706	98.9	Polar/Sun-synchronous	98.9	0945
Geosat	1985	800	108.0	General	100.7	NA
SPOT	1985	832	98.7	Polar/Sun-synchronous	101.46	1030
IRS-1	1985	904		Polar/Sun-synchronous		
DMSP/ATN	1985	837	98.8	Polar/Sun-synchronous	101.6	1000
MOS-1	1986	909	99.1	Polar/Sun-synchronous	103.2	1000-1100
ERS-1	1988	777	98.5	Polar/Sun-synchronous	100.5	1015
N-ROSS	1981	830	98.7	Polar/Sun-synchronous	101.0	0715
TOPEX	1981	1334	63.4	General	112.4	NA
NOAA-Next	1981	821	98.8	Polar/Sun-synchronous	102.0	0730 and 1300 (2-satellite system)
Radarsat	1990	1001	99.5	Polar/Sun-synchronous	105.2	0944

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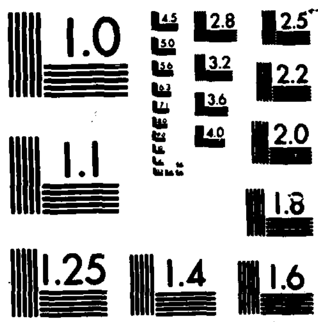

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

APPENDIX C

OPERATIONAL POLAR-ORBITING

ENVIRONMENTAL SATELLITE HISTORY

APPENDIX C

POLAR ENVIRONMENTAL SATELLITE HISTORY

TIROS Series (1960-67	Lifetime
TIROS-1	2 mo.
TIROS-2	3 mo.
TIROS-3	3 mo.
TIROS-4	5 mo.
TIROS-5	12 mo.
TIROS-6	14 mo.
TIROS-7	32 mo.
TIROS-8	43 mo.
TIROS-9	25 mo.
TIROS-10	24 mo.

ESSA Series (1966-73	Lifetime
ESSA-1	15 mo.
ESSA-2	56 mo.
ESSA-3	24 mo.
ESSA-4	12 mo.
ESSA-5	34 mo.
ESSA-6	24 mo.
ESSA-7	12 mo.
ESSA-8	87 mo.
ESSA-9	57 mo.

ITOS Series (1970-79)	Lifetime
ITOS-1	18 mo.
NOAA 1	8 mo.
NOAA 2	26 mo.
NOAA 3	33 mo.
NOAA 4	48 mo.

TIROS-N Series (1979-Present)	Lifetime
TIROS-N	28 mo.
NOAA 6	73 mo.(1)
NOAA 7	49 mo.(1)
NOAA 8	27 mo.(1)
NOAA 9	4 mo.(1)

(1) Still in operation.

APPENDIX D

GLOSSARY OF ACRONYMS

ADCLS	-	Automated Data Collection and Location System
ALT	-	Radar Altimeter
AMI	-	Active Microwave Instrument
AMR	-	Advanced Microwave Radiometer
AMSU	-	Advanced Microwave Sounding Unit
APACM	-	Atmospheric Physical and Chemical Monitor
APT	-	Automatic Picture Transmission
Argos	-	French Data Collection and Platform Location System
ATN	-	Advanced TIROS-N
ATOVS	-	Advanced TIROS Operational Vertical Sounder
ATSR	-	Along-Track Scanning Radiometer
AVE	-	Aerospace Vehicle Electronics
AVHRR	-	Advanced Very High Resolution Radiometer
CEOS	-	Committee on Earth Observations Satellite (previously IEOSC)
CLOS	-	Coordination of Land Observing Satellites
CORSS	-	Coordination of Ocean Remote-Sensing Satellites
CZCS	-	Coastal Zone Color Scanner
DE	-	Dynamics Explorer
DMSP	-	Defense Meteorological Satellite Program
DOD	-	Department of Defense
DSB	-	Direct Sounder Broadcast
E-Alt	-	ERS-1 Altimeter
ELV	-	Expendable Launch Vehicle

EOS	-	Earth Observing System
ESA	-	European Space Agency
ERBE	-	Earth Radiation Budget Experiment
ERBI	-	Earth Radiation Budget Instrument
ERBS	-	Earth Radiation Budget Satellite
ERS-1	-	ESA Remote Sensing Satellite
ERTS-A	-	Earth Resources Technology Satellite
ESMR	-	Electrically Scanning Microwave Radiometer
ESSA	-	Environmental Science Services Administration
GEOS	-	Geodynamics Experimental Ocean Satellite
GEOSAR	-	Geologic Synthetic Aperture Radar
GEOSAT	-	Geodetic Satellite
GOMR	-	Global Ozone Monitoring Radiometer
GPS	-	Global Positioning System
HCCM	-	Heat Capacity Mapping Mission
HIRIS	-	High Resolution Imaging Spectrometer
HIRS	-	High Resolution Infrared Radiation Sounder
HMMR	-	High Resolution Multifrequency Microwave Radiometer
HRPT	-	High Resolution Picture Transmission
HRV	-	High Resolution Visible Range Instrument
IEOSC	-	International Earth Observation Satellite Committee (presently CEOS)
IGBP	-	International Geosphere-Biosphere Program
IPOMS	-	International Polar-Orbiting Meteorological Satellite Group

IRS-1	-	Indian Remote-Sensing Satellite
ITOS	-	Improved TIROS Operational Satellite
JERS	-	Japan Earth Resources Satellite
LAMMR	-	Large Antenna Multichannel Microwave Radiometer
Landsat	-	Land Satellite
LASA	-	Lidar Atmospheric Sounder and Altimeter
LFMR	-	Low-Frequency Microwave Radiometer
LIMS	-	Limb Infrared Monitor of the Stratosphere
LISS	-	Linear Imaging Self-Scan Cameras
MAPS	-	Measurement of Air Pollution From Satellites
MEPED	-	Medium Energy Proton and Electron Detector
MESSR	-	Multispectral Electronic Self-Scanning Radiometer
Metsat	-	Meteorological Satellite
MLA	-	Multispectral Linear Array
MODIS	-	Moderate-Resolution Imaging Spectrometer
MOS-1	-	Marine Observation Satellite
MRIR	-	Medium-Resolution Imaging Radiometer
MSR	-	Microwave Scanning Radiometer
MSS	-	Multispectral Scanner
MSU	-	Microwave Sounding Unit
NASA	-	National Aeronautics and Space Administration
Nimbus	-	Meteorological Observation Satellite
NOAA	-	National Oceanic and Atmospheric Administration
NOAA-NEXT	-	Next Generation of NOAA Satellites
NOSS	-	National Oceanic Satellite System

N-ROSS	-	Navy Remote Ocean Sensing System
NSCATT	-	N-ROSS Scatterometer
NSF	-	National Science Foundation
OCI	-	Ocean Color Imager
OLS	-	Operational Linescan System
OMV	-	Orbital Maneuvering Vehicle
OTV	-	Orbital Transfer Vehicle
RA	-	Radar Altimeter
Radarsat	-	Radar Satellite
RAS	-	Radar Altimeter System
RBV	-	Return Beam Vidicon
SAM II	-	Stratospheric and Aerosol Measurement II
SAMS	-	Stratospheric and Mesospheric Sounder
SAP	-	Sensor AVE Package
SAR	-	Synthetic Aperture Radar
SAR	-	Search and Rescue
SARSAT	-	Search and Rescue Satellite
SASS	-	Seasat-A Scatterometer Sensor
SBUV	-	Solar Backscatter Ultraviolet Radiometer
SCAMS	-	Scanning Microwave Spectrometer
SCATT	-	N-ROSS Scatterometer
SEASAR	-	Sea Synthetic Aperture Radar
Seasat	-	Sea Satellite
SEM	-	Space Environment Monitor
SIR	-	Shuttle Imaging Radar

SISEX	-	Shuttle Imaging Spectrometer Experiment
SMM	-	Solar Maximum Mission
SMMR	-	Scanning Multichannel Microwave Radiometer
SPM	-	Solar Proton Monitor
SPOT	-	Systeme Probatoire d'Observation de la Terre
SR	-	Scanning Radiometer
SSE	-	Special Sensor E
SSM/I	-	Special Sensor Microwave Imaging
SSM/T	-	Special Sensor Microwave Temperature Sounder
SSM/T-2	-	Water Vapor Sounding System
SSU	-	Stratospheric Sounding Unit
STS	-	Space Transportation System
T-Alt	-	TOPEX Altimeter
TDRS	-	Tracking and Data Relay Satellite
TDRSS	-	Tracking and Data Relay Satellite System
TED	-	Total Energy Detector
THIR	-	Temperature-Humidity Infrared Radiometer
TIROS-N	-	Television and Infrared Observation Satellite
TM	-	Thematic Mapper
TOMS	-	Total Ozone Mapping Spectrometer
TOPEX	-	Ocean Topography Experiment
TOS	-	TIROS Operational Satellite
TOVS	-	TIROS Operational Vertical Sounder
UARS	-	Upper Atmosphere Research Satellite

USAF	-	United States Air Force
VHRR	-	Very High Resolution Radiometer
VIRR	-	Visible and Infrared Radiometer
VTIR	-	Visible and Thermal Infrared Radiometer
VTPR	-	Vertical Temperature Profile Radiometer
Windsat	-	Wind Satellite (Doppler Lidar Wind Sensor)
WOCE	-	World Ocean Circulation Experiment

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